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Health Technologies as a Cost-Driver in Canada
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Executive Summary

This report describes our estimation of the effects of technological change (TC) on health care (HC) expenditures in Canada during the period 1996-2008. We focus on the effect of TC on overall nominal expenditures, as well as the effects of TC on prescription drug expenditure and all other (non-drug) HC expenditure.

Estimation is complicated by the fact that it is not possible to directly estimate the "stock" of health technology in the non-drug sector without very detailed data on the myriad forms of diagnostic, therapeutic, preventative and palliative healthcare used today. Health technology involves drugs, medical equipment, devices and other tangible items as well as procedures, techniques and other forms of "know how". As such, health technology is exceedingly heterogeneous and not directly comparable. The same problems bedevil direct estimation of expenditures on health technology.

Because we cannot directly measure the "stock" of health technology, we need to estimate the effect of health TC on HC spending indirectly. We estimate this as the component of health care spending growth that remains after subtracting the growth in health care spending due to population growth, inflation, demographic change and other readily quantifiable cost drivers. This technique is known as the "residual" approach. A defect of the residual approach is that it is possible that time-varying factors other than TC are absorbed in the residual.

To implement this, we estimated regression models of prescription drug spending and non-drug spending using province-year level data obtained from the Canadian Institute for Health Information (CIHI). These models allowed us to directly estimate the role of standard cost drivers (i.e. population growth, inflation, demographic change, income) and a residual component, which was modelled as a set of year specific indicator variables. The estimates of these year indicators on spending, known as "year effects", capture the changes over time in the "residual" expenditures that are common to all provinces. We supplemented this regression-based analysis with an accounting-based analysis, in which we used estimates of the effect of standard cost drivers produced by others.

Our regression models suggest that TC explains 45% of the growth in prescription drug spending and 37% of the growth in other (non-drug) healthcare spending over the period 1996-2008. Non-drug spending accounts for the majority of total HC spending; thus we estimate that TC explains 38% of the growth in total HC spending over the period. TC in the prescription drug and non-drug sectors is estimated to have increased HC spending by $5 billion and $23 billion, respectively, over the period 1996-2008.

Our accounting-based estimates are less precise. They suggest that TC explains between 27 – 49% of total real per capita HC costs over the period 1996-2008, depending on the income elasticity used and ones assumptions regarding the level of excess medical price inflation. This uncertainty likely reflects the fact that time-varying factors other than TC are absorbed in the residual. Nevertheless, our regression models did appear to be valid. The growth in the year effects was highly correlated with observed measures of TC,

spending on MRIs, CT scans and other diagnostic imaging performed in Canadian hospitals since 1998. Moreover, the 38% estimate is very close to an independent estimate for Canada for the period 1975-2000, and an estimate for Australia over the period 1992-93 to 2002-03. The estimate of the impact of TC on prescription drug spending is consistent with estimates produced by the Patented Medicine Prices Review Board.

We conclude that TC in the non-drug sector is financially significant, and it is thus worthwhile to assess value for money spent on new technologies. We recommend that CIHI track spending on new procedures in both the inpatient and ambulatory care sectors. This can be done using their existing data holdings, and would help prioritize the technologies that are subject to economic appraisal.

Introduction

As described in our successful proposal to Health Canada, we conduct research into the effects of technological change (TC) on health care (HC) expenditures in three stages, as described below.

Stage 1: We search the relevant published and grey literatures using the considerable resources of the University of Toronto library system to identify, first, approaches to estimating the effect of TC on expenditures on both prescription drug and on the other components of HC, and second, empirical evidence on this question. We compare different approaches in respect of their data requirements, estimator precision and bias, and suitability to the task at hand. We then determine which approaches seem promising for our study. We also review the reliability and limitations of existing empirical evidence and their applicability to the Canadian scene.

Stage 2: We are familiar with most of the databases from the Canadian Institute for Health Information (CIHI), the Statistics Canada CANSIM, IMS Health and the OECD. Our preliminary catalog of the most relevant of these data was set out in Appendix 1 to the proposal. It seems probable that these data will be used for the proposed study. Nevertheless, it is possible that we become aware of additional data sources germane for the study through our scoping exercise in Stage 1. We assess the quality of the different data and consider which data sets and approaches are best suited for the task at hand.

Stage 3: Using the preferred set of methods and data identified from our work in Stages 1 and 2, we:

1. estimate a so-called "residual model" to the Canadian context to assess the impact (% contribution) of TC (total and broken down into its pharmaceutical and non-drug components) to the annual rise in health care spending over at least the past 5-10 years;
2. analyse whether the cost contributions are changing over the studied period and if so, produce empirical estimates of how they are changing;
3. provide an estimate of the level of annual expenditure on TC (total and broken down into its pharmaceutical and non-drug components) and discuss results in comparison to total health care spending in Canada;
4. discuss possible future work that could examine the cost-efficiency of health technologies in terms of improved health outcomes;
5. present the main findings via teleconference and deliver a final written document, which includes an executive summary, an introduction section, a body of text reporting on findings from the three stages, and a brief conclusions section that reflects policy recommendations.

This report describes the work completed on all 3 Stages.

Overview of the empirical approaches to estimate the effect of TC on HC costs

There is now a sizeable empirical literature assessing the contribution of TC on HC costs. Two methods are routinely used – the "residual" approach and the "direct" approach.[1] To use the residual method, one estimates the impact of population growth, demographic change, price inflation and other known and readily quantifiable cost drivers on HC costs. Growth in HC spending beyond what is expected by the growth in these measurable determinants is referred to the residual. The change over time in the residual is used as an estimate of the effect of TC on HC costs. A defect of this approach is that the residual may reflect factors other than TC, including, for instance, the productivity of health care providers, changes in the capacity of the HC system, changes in the intensity of service use and changes in the pattern of disease. This perhaps explains why estimates of the effect of TC on HC costs from studies that have used the residual approach with Canadian data are quite variable.[2]

As the name implies, the direct approach attempts to quantify TC, and directly estimate the effect of measured TC on HC costs. Studies that assess the consequences of pharmaceutical innovation, for instance, commonly measure TC using the number of new molecular entities approved for use in the United States (US). Quantifying TC outside of the pharmaceutical sector, however, is much more challenging owing to the fact that there are so many forms of technology at play. TC consists of the introduction of new tangible pieces of equipment (such as a new diagnostic imaging device, or a new prosthetic) or new techniques or procedures ("know-how") to prevent, diagnose, treat, or palliate health problems. This admits a large array of goods and services. This includes, *inter alia*, diagnostic procedures, tests and equipment, such as tests for the presence of cancer, tests of the functioning of the cardiovascular, hepatic, endocrine and other systems, tests for parasitic, bacterial and viral infection, X-ray machines, angiography, magnetic resonance imaging (MRI), nuclear magnetic resonance imaging (NMRI), magnetic resonance tomography (MRT), X-ray computed tomography (CT) imaging; surgical procedures and equipment, such as laparoscopic surgery, bypass surgery, hip and knee replacement surgery, hernia repair, implantation of cardiac pacemakers, as well as related anaesthetic techniques; non-surgical therapeutic interventions, such as *in vitro* fertilisation, wound care, physiotherapy, osteopathy, chiropractic and other rehabilitation techniques, filling of dental caries and related forms of dental care, intensive care (including neo-natal, pediatric, and cardiac forms); cognitive therapies used in psychiatric

[1] One could also address the question using the 'case-study' approach, i.e. estimate the costs and benefits of a specific health technology (or a specific medical condition and its associated treatments). While this is informative, this approach requires studying many diseases to draw conclusions about the impact of TC as a whole on total HC expenditure. Given that our focus here is assessment of the impact of health technologies generally on pharmaceutical and non-pharmaceutical expenditures, we do not review these studies. Interested readers can refer to an excellent review of the case-study approach in the Australian Competitiveness Committee's 2005 report and also Chernew (2011). Representative studies using this approach include Cutler and McClellan (2001), Baker et al. (2003), Cutler (2007), Barbash and Glied (2010).

[2] Constant, Peterson, Mallory, and Major (2010). Research synthesis on cost drivers in the health sector and proposed policy options. Canadian Health Services Research Foundation, March 2011.

and psychological treatment; and the "hotel" care offered to institutionalized patients, such as pressure-distributive mattresses. We could also include here: information management systems used in the provision of healthcare, such as electronic medical records; clinical decision making rules and paradigms, such as those used in the practice of evidence based medicine; as well as the methods used to educate and train physicians, pharmacists, nurses, dentists and other health professionals.

Global measures of the stock of technology in the hospital and ambulatory care sectors, and associated spending on these technologies, are thus bound to be very noisy and imperfect measures. The statistical problems associated with measurement error in a covariate are well known: this introduces bias into conventional estimators of model parameters, a problem that does not go away with increases in sample size.

The choice between the residual and direct approaches is thus a choice between the indeterminacy of the residual (in that it reflects the combined effect of TC and other unmeasured trending factors) and the bias and inconsistency in estimates of the impact of mismeasured TC on HC costs. Our view is that the residual approach is the lesser of the two evils. Because the degree and direction of estimator bias in the direct approach is simply unknown, it is difficult to interpret one's results. The residual approach, on the other hand, is more informative. One could account for the influence of unmeasured trending factors either directly (by attempting to explicitly quantify and then control for these factors) or indirectly (by using qualitative or other information on the impact of these factors on HC costs). Moreover, one can perform various sensitivity checks on the residual model. For instance, should there be some quantifiable measure(s) of TC then, assuming that TC is cost increasing, adding these controls for TC in the model should reduce the size of the residual component. This should be the case even if these controls do not adequately measure all domains of TC. If the residuals do become smaller after controlling for TC, then there is some evidence that the residuals are in fact capturing the influence of TC.

Literature review

We next describe our review of the key studies in the literature.

Studies that have used the direct approach

While our focus is on studies that have employed the residual approach, we briefly describe at the onset two prominent studies that have used the direct approach. These studies are Okunade and Murthy (2002) and the 2005 Australian Productivity Commission (APC) report.

Okunade and Murthy (2002) examine the major drivers of per capita real HC expenditure in the US during the period 1960–1997. They measure TC using US total research and development (R&D) expenditure as well as R&D expenditure in the health sector only. Using these data they test and establish the stable long-run (i.e. co-integrated) relationship[3] between real US health expenditure per capita, real GDP per capita and

[3] Hansen and King (1996) show that the estimated relationship between two time series may be spurious unless these two variables have a long-term relationship (technically, they are

broad-based R&D expenditures (i.e. total and health-specific R&D). They estimate the elasticity of US per capita health expenditure with respect to expenditure on health R&D technological change to be 0.32. This means that 1 per cent increase in expenditure on health R&D leads to a 0.32 per cent increase in real per capita health expenditure.

More recently, the APC (2005) estimated the impact of health technology on Australian total HC expenditure for the period 1992-93 to 2002-03. Like Okunade and Murthy (2002), they also use the US health sector's R&D spending as a proxy for health technological change. They also control for other determinants of heath care costs including GDP growth, the proportion of the population older than 65, and the proportion of the population with private insurance. Their cointegration analyses confirm the long-term relationship between health expenditure, GDP, private health insurance coverage and health R&D spending. They estimated the elasticity of real HC expenditure per capita with respect to technological change to be 0.25. Multiplying this elasticity with the growth rate in US health R&D over the last decade, they obtain an estimate of the impact of technological change on HC expenditure growth over the last ten years. The result indicates that technological changes account for 1.9 percentage points in the annual growth of 5.3 per cent in real HC expenditure in Australia over the period 1992-93 to 2002-03. Hence TC is estimated to account for $1.9/5.3 \times 100 \approx 36\%$ of HC spending growth over this period.

Studies that have used the residual approach

Residual-based studies can be subdivided into two types: those that generate original estimates of the effect of demographic change, income growth and other cost-drivers on HC costs and those that rely on estimates produced by others. The former type, which we call the "regression-based residual approach", is the focus of our literature review given that we will be using this approach to address study objectives. The canonical approach is to estimate a linear regression model of HC expenditures on a set of known cost drivers, including demographics, income, and price inflation, as well as variables intended to capture the residual component. Which variables are used to capture the residual depends on the kind of data available. If annual time series data are available then a time trend (either linear or low-order polynomial) is the only option. If, on the other hand, panel data are used, then more options are available. Panel data consist of data in which a number of different provinces, countries or other cross-sectional units are observed at different points in time. Using panel data, one can estimate the residual component (and associated standard errors) with either a time trend or with a set of year-specific binary indicator variables, commonly referred to as "year dummies". The linear time trend approach is the most restrictive in that the unmeasured time-varying factors are forced to have an identical absolute (or, depending on model specification, identical proportional) effect of HC costs each period. Year dummies do not impose any such constraints; they mop up the effects on HC of any time-varying factors that are common to all cross-

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cointegrated). In response to this critique, subsequent time series empirical studies often test the variables used for the cointegration using techniques such as unit root testing, cointegration and error correction models.

sectional units each period. Presumably TC is an important (perhaps the dominant) time-varying factor but it likely is not the only factor.

We note in passing here that some studies that we encountered in the literature did not explicitly control for time-varying residual factors in the regression model, preferring instead to interpret the *regression residual* (that is, the observed less predicted value of HC costs) as reflecting the effect of TC. This approach is problematic because failure to control for TC in the regression model might bias ones estimates of the impact of the cost drivers on HC costs. This would be the case if there is any correlation between the known cost drivers and TC. But we believe that this is likely; it is almost certainly the case that there is correlation between income and population growth and TC.

The other type of residual-based study, those that rely on estimates produced by others, could be called the "accounting-based residual approach". This approach is mostly closely associated with Joseph Newhouse' seminal 1992 article, which argued that TC was the dominant driver of HC cost growth in the US over the previous 6 decades. This method is best explained by taking the total derivative of the function posited to determine HC costs. Suppose, for concreteness, that HC costs, denoted as "*HCC*", depends on some unknown function f(.) of three known, quantifiable cost drivers, x_1, x_2 and x_3, and TC. This function can be expressed as:

$HCC = f(x_1, x_2, x_3, TC)$

The total derivative of this function is:

$dHCC = f_{x1}\, dx_1 + f_{x2}\, dx_2 + f_{x3}\, dx_3 + f_{TC}\, dTC$

where $f_{x1} = \partial f(x_1, x_2, x_3, TC)/\partial x_1$, the partial derivative of $f(x_1, x_2, x_3, TC)$ with respect to x_1 and dx_1 is an infinitesimally small change in x_1. The other terms are defined analogously. This equation says that a change in HC costs can be decomposed as the sum total of the changes in the respective cost drivers times their respective "partial effects" on costs. This equation is strictly valid only for very small changes in cost drivers, so that if we wish to contemplate the effects of the discrete changes in cost drivers actually seen in the data, then the equation is an approximation. Re-arranging this approximation formula allows one to estimate the influence of TC on HC costs using data on observed changes in *HCC* and the cost drivers, x_1, x_2 and x_3, (denoted by ΔHCC, Δx_1, Δx_2, Δx_3, respectively) as well as estimates of the partial effects of these cost drivers on *HCC*, denoted as f_{x1}, f_{x2}, and f_{x3}:

contribution of TC to $HCC \approx \Delta HCC - [f_{x1}\, \Delta x_1 + f_{x2}\, \Delta x_2 + f_{x3}\, \Delta x_3]$ equation (1)

The accompanying excel spreadsheet entitled "literature review results.xls" summarizes some of the findings of the literature that have used the accounting-based residual approach to estimate the influence of TC on HC costs. These can be found in the worksheet labeled "accounting models". A defect of the accounting-based residual approach for our purposes is that the estimates of the partial effects need to be borrowed from other studies. Estimates obtained from these studies may not adequately reflect the situation in Canada over the last two decades, which is the focus of the present analysis. It thus seems preferable to obtain original estimates of these partial effects using the relevant data.

A comprehensive summary of all regression-based residual studies deemed relevant for our purposes appears as the worksheet "residual reg models" in the accompanying excel spreadsheet. Existing studies use panel data consisting of either Canadian provinces or OECD countries over different time periods spanning the last four decades. Most studies focus on total public HC spending (some on total public + private spending). None model pharmaceutical and non-pharmaceutical HC spending separately. Cost drivers were modeled as follows:

Population size

All studies normalized their models by expressing HC spending and covariates, where appropriate, in per capita terms. Note that this normalization assumes that a 1% increase in population size increases spending by 1%. In other words, the elasticity of HC spending with respect to population is assumed to be equal to one. This assumption, while not formally tested, seems reasonable.

Demographics

All studies control for demographic change using the fraction of the population in various age groups. DiMatteo (2005) uses the richest specification, controlling for the proportion of the population aged 0–17, 18–44, 45–64, 65–74 and 75 plus.

Income

Most studies control for income using gross domestic product (GDP); DiMatteo (2005, 2010) adds controls for federal cash transfers to the provinces (which is an important source of revenues for some provincial governments in Canada). DiMatteo (2010) adds dummy variables indicating periods during which different federal-provincial social program financing agreements were in effect. These agreements include the Canada Health Act, the Established Program Financing (EPF) agreement, the Canada Health and Social Transfer (CHST), and the agreement in which the Health Transfer and Social Transfer were provided in separate envelopes (thereby effectively constraining the provincial funds available to fund health programs).

Ariste and Carr (2002) measured the combined income available to the primary purchasers of HC in Canada, individual households and provincial governments. Personal disposable income was measured as GDP less taxes paid by individuals and businesses. Provincial government income was measured as their tax revenues plus federal transfer payments. Their decision to measure personal income was somewhat curious given that their outcome variable was publicly funded HC spending.

Healthcare price inflation

Measurement of HC price inflation requires that one isolate the pure price component from price increases that are attributable to higher quality. Given the difficulty in measuring and controlling for HC quality, most of the studies that we reviewed used either the GDP deflator or the Government Current Expenditure Implicit Price Index. These variables measure inflation in a large basket of goods and services – not just those in the health care sector. This approach rests on the assumptions that: 1) these variables capture pure price inflation and 2) that this price inflation affects prices in the healthcare sector.

Other cost-drivers

DiMatteo (2004) used the number of physicians per capita, and the private share of total HC expenditure.

Residual component

With one exception, all studies used a linear time trend. The exception was DiMatteo (2005), who used year dummies. DiMatteo (2010) used a separate time trend for each province. Most studies include country- or province-specific dummy variables to allow for time-invariant differences in HC spending between regions.

Evidence on the effect of TC on pharmaceutical expenditures

With the right data, it is possible to assess the effects of new drug launches on prescription drug spending more directly, without the need for residual modeling, using index-based methods. Professor Steve Morgan from the University of British Columbia has conducted such research using dispensing-level data from IMS Health and the BC Pharmanet (a database of all prescription drugs dispensed in BC). His work has highlighted the importance of TC in prescription drug cost growth. For instance, using Pharmanet data, he found that, between 1996 and 2002, relatively new, patented drugs deemed to be comparable to medicines brought to market prior to 1990 had accounted for 80 percent of expenditure growth in the province (Morgan 2005).

In a recent review article (Morgan 2008), Morgan summarizes the key findings of this literature. He notes that substitutions of new for older drugs, often referred to as product "mix," accounts for between 15 and 40 percent of drug cost growth. To cite but one example from his review, a Canadian study (PMPRB 2002) found that the sales growth of drugs during their first two years on the market accounts for between 19 and 44 percent of all cost escalation under provincial drug plans. Public drug plans cover about 45% of prescription drug costs in Canada; private plans cover about 38% and direct household spending the remainder. Because the private plans appear to be less restrictive in their coverage of new drugs than the public plans, we can expect that the contribution of TC to cost growth in private plans to be at least as large as that observed for the public plans.

Our methods

We next describe how we estimate the regression-based residual models. The Canadian studies have all used HC expenditures data obtained from the Canadian Institute for Health Information (CIHI) National Health Expenditures (NHEX) Database. We do the same, using data over the last 24 years (1985-2008). These data appear to be of high quality. (The 2009 and 2010 figures are still provisional and therefore are not used.) Table 1, below, presents data on health care expenditures for the year 2008.

Table 1 Expenditures on health care, by type of health care and payer type, Canada, 2008

	provincial government	other public	private	total	
Hospitals	44,265.3	665.0	4,446.3	49,376.6	30%
Other Institutions	12,013.2	118.3	4,844.5	16,976.0	10%
Physicians	22,053.0	488.9	390.3	22,932.2	14%
Other Professionals	775.9	584.9	17,162.0	18,522.8	11%
Prescription Drugs	9,239.7	1,570.4	12,634.9	23,445.0	14%
Capital	6,440.2	346.0	1,406.3	8,192.5	5%
Public Health	8,960.1	2,091.0	0.0	11,051.0	7%
Administration	1,515.1	1,029.1	3,291.8	5,836.0	3%
Other Health Spending	6,495.6	2,400.7	2,032.8	10,929.1	7%
Total	111,758.0	9,294.1	46,209.0	167,261.1	100%
	67%	6%	28%	100%	

Note: expenditures reported in millions of dollars. Data Source: Canadian Institute for Health Information National Health Expenditures Database

We model province and year specific values of total (public + private) health care costs as a function of various readily quantifiable determinants of health care costs. Separate linear regression models are estimated for spending on two HC categories, prescription drugs, and "non-drug", which comprises the sum total of spending on hospitals and other institutions (inpatient care) plus spending on physicians and other health professionals (ambulatory care) plus spending on over the counter drugs, capital, public health, administration and other items. From Table 1, inpatient and ambulatory care collectively constitute the majority (about 65%) of total health care spending.

The Baseline Models

Several sets of regression models are estimated. The first of these, the "baseline models", specify category-specific expenditures to be a function of demographic variables, income, and price inflation; these variables appear in almost all residual models we have seen in the literature. We quantify the cost drivers in these baseline models as follows:

Population size

We follow the literature and express HC spending and covariates, where appropriate, in per capita terms. Population counts, by age, sex, province and year are available from the Statistics Canada CANSIM.

Demographics

We control for the proportion of the population aged 0–4, 5–19, 20–44, 45–64, 65–74 and 75 plus. There is good evidence that HC costs are highest for the very young (0-4), and very old (75+) and this specification is sufficiently flexible to capture this. It is possible that there are no big differences in HC costs among the 5–19, 20–44, and 45–64 groups; we will formally test using F-tests, and if so, collapse these groups. The number of covariates we add to the model is given in square brackets: [6 covariates]

Income

Given that HC spending in Canada reflects the decisions of (primarily) provincial governments and households, we consider the resource constraints affecting both decision makers. We prefer an expenditure based (budgetary) measure to an income-based measure. Because a decision maker's annual budget on goods and services reflects the effects of saving, borrowing and transfers, it better reflects the decision maker's anticipated permanent income, including prior savings and anticipated future income, and is less variable than its current income. In the models of total (public + private) expenditure, we include both provincial government and household expenditure covariates. [2 covariates]

We compared time series graphs of real per capita HC spending, the budgetary resource measures and the conventional income measures used in other studies. We find that the budgetary measures better capture the effects of fiscal constraint observed over the period 1990-1996, and the fiscal expansion observed from 1996 to 2008.

CANSIM Table 384-0002 contains data on expenditure-based gross domestic product, by province and year. From this table, we select personal expenditure on consumer goods and services (minus expenditure on durables) and net government current expenditure on goods and services.[4]

Healthcare price inflation

We follow DiMatteo (2010) and use the Government Current Expenditure Implicit Price Index to deflate inpatient and ambulatory care expenditures. We recognize that this is not a perfect measure of HC price inflation but this appears to be the best of what is available. For the prescription drug expenditure models, we will use a price index constructed by the Patented Medicine Prices Review Board (PMPRB); the PMPRB is an independent quasi-judicial regulatory agency established by Parliament in 1987 under the *Patent Act*. The PMPRB created the Patented Medicines Price Index (PMPI) to monitor trends in prices of patented drug products. The PMPI is a price index measuring the average year-over-year change in the ex-factory prices of patented drug products sold in Canada. The PMPI does not measure price changes of non-patented drugs (which describes most generic drugs). However, generic drug prices are regulated by most drug

[4] http://www5.statcan.gc.ca/cansim/pick-choisir?lang=eng&searchTypeByValue=1&id=3840002

plans to be some fixed fraction of the price of the reference branded drug. Thus both generic and brand prices should increase at rate no greater than the rate of increase of the PMPI. A remaining component of drug costs, which again is not tracked by the PMPI, are wholesale and retail markups and fees (including pharmacist professional fees). While it is possible that this component increases at a rate greater than the PMPI, the measurement error introduced should be modest. The reason is that industry sources informed us that these markups and fees represent at most 15% of prescription drug costs.

Residual Component

The models will also contain year-specific dummy variables. The year dummies reflect the changes over time in expenditures that are common to all provinces. Estimates of the coefficients on the year dummies (which we call "year effects") will thus reflect the influence of TC (and other factors that trend over time) on HC costs. The primary attraction of the year dummies over a linear time trend is that the dummies do not constrain the impact of TC to have a time invariant impact on HC costs. We can thus address the requirement on page 3 of the Health Canada RFP that "To the extent possible, analysis should examine if and how the cost contributions are changing over time." [23 dummies]

In addition to the year dummies, we include province-specific dummies to capture time-invariant differences in levels of HC expenditure by province. [9 dummies]

The Augmented Models

The next set of models – the "augmented models" – account for additional factors that constrain HC expenditures. Chief among these is the capacity of the HC system, as measured by the number of health care providers, and the number of hospital beds. Provider supply would include, *inter alia*, the number of full time equivalent (FTE) general practitioners and specialist physicians. The health economics literature has long recognized that health care providers will expand service offerings (or "meet all needs") up to capacity constraints. (This literature has given us the dictum that "a built bed is a filled bed"; it has also given us the concept of "supplier induced demand".)

One might question why these capacity constraints need to be explicitly modeled, given that we already control for budget constraints (i.e. the size of the government and personal outlays on (non-durable) goods and services). Indeed, one could argue that the HC system capacity constraints are in the middle of the "causal pathway" between decision maker budgets and HC spending. The answer is that these capacity constraints can be thought of as stock variables that evolve only slowly over time. It takes years for new hospitals to be built and new physicians to be trained. Thus, even if budgets increase, one cannot instantaneously expand HC spending by the same amount.

We measure the number of physicians by type, both primary care (general practitioners and family physicians combined) and specialists. We use Scott's Medical Database for this task. (The other source of physician supply data, CIHI's National Physician

Database, is not suitable given that it surveys only those physicians paid fee-for-service. These data are also unavailable for our entire study period.) [2 covariates]

We requested CIHI data on the number of hospital beds (acute care and psychiatric) by province and year that are fully staffed and in operation. Unfortunately, data on hospital beds staffed and in operation are available for only three fiscal years (2006-2007, 2007-2008 and 2008-2009). We were thus unable to use these data in our models.

The Validation Models

The third set of models – the "validation models" – add to the augmented models several covariates that proxy TC. The idea here is that changes in the size of the year dummy estimates following the inclusion of these TC proxy variables reflect how well the year dummies reflect the effects of TC in the augment models. In particular, if the year dummies become smaller with the TC proxies included in the regression, there is some evidence that the dummies are in fact capturing the influence of TC. These models, then, serve as check of the validity of the residual approach.

The type of TC proxies that we include depends on the type of HC expenditure that we are modeling. For the non-drug expenditure models, we use data collected by CIHI's National Survey of Selected Medical Imaging Equipment. In particular we will use the number of computed tomography (CT) scanners, and magnetic resonance imaging (MRI) scanners for the years 1991-2007, and 2009 (the data are unavailable in 2008). There is also data on the number of other diagnostic imagers by province and year, including nuclear medicine cameras, angiography suites, catheterization labs, positron emission tomography (PET) scanners, and positron emission tomography – computed tomography (PET/CT) scanners. Unfortunately these data are available only for several years, 2003 – 2008; it is not possible to estimate the regression models with an acceptable degree of precision using such a short time period. We are unaware of any additional TC proxies that can be used to explain growth in spending on services rendered by physicians' and other health professionals.

For the prescription drug expenditure models, we can, in principle, include (lagged values of) the number of new molecular entities approved for use by Health Canada as a very crude measure of TC. These data are available in Health Canada's Drug Product Database (DPD).[5] We do not believe that this approach is a good test of the validity of the drug expenditure models. The limitation with this approach is that new drug approvals are national in scope whereas the data that we have are province-specific, and provincial coverage of new drugs is known to vary widely. Another limitation is that, as Morgan (2008) notes: "Much of the growth in prescription drug expenditure observed in recent years has been accounted for by a disproportionately small number of medications. Claims data from the United States from 2000-2001 has shown that half of the expenditure growth occurred in only nine categories of drugs, and half of the spending increase was driven by increases in the sales of 27 relatively new drugs." In other words, there is substantial heterogeneity among new molecules in their potential to increase drug costs. It appears that most additional spending is accounted for by a small number of

[5] http://webprod.hc-sc.gc.ca/dpd-bdpp/index-eng.jsp

new drugs. For these reasons, we elected to not run the prescription drug expenditure validation model, as it provides a very unreliable test of the quality of the augmented model. We did, however, directly estimate the effects of lagged new drug introductions on prescription drug expenditures using national level data.

The accounting-based residual approach

These linear regression models constitute the "econometric" approach to estimating the residual models. Another way of proceeding can be described as the "accounting" approach. This method uses: 1) estimates of the effect of demographics, income, medical price inflation and other factors on health care expenditures obtained from the academic literature; and 2) data on the rates of growth of these factors in Canada to estimate the component of the growth of Canadian HC expenditures that is due to these factors. The residual growth in Canadian HC expenditures is attributed to TC. These elasticity estimates, summarized in the worksheet "accounting models" in the accompanying literature review spreadsheet, were derived from jurisdictions that have substantial levels of public sector HC funding and also have similar levels of economic development, and national income as Canada.

The regression-based residual approach using OECD data

Finally, we estimate the augmented residual models (described above) using data on health care expenditures, demographics, income, GDP deflators, physician and hospital bed density from a variety of OECD countries. We model the residual using a country-specific linear time trend. These models produce country-specific estimates of the effect of TC on HC expenditures. The OECD Health data also contains some information on the level of adoption of medical technology (including the supply of computed tomography scanners and magnetic resonance imagers). We select the estimates of the effect of TC on HC expenditures of Canada and other OECD countries with a similar level of apparent medical technology adoption and compute a population size-weighted average of these estimates.

Unfortunately, the reliability of the evidence obtained from this approach is limited by two factors. First, there will likely be a lot of unobserved differences in HC cost growth across countries and this will make it difficult to get precise estimates. Second, our reading of the literature suggests that there are problems with standardizing data collection across these countries, as each country has adopted slightly different accounting conventions. Certainly, the OECD Health data appear to be less reliable than the CIHI NHEX data that we will rely on for our primary estimates.

Synthesis of the evidence

Each of these three approaches, the econometric analysis of province-year level HC cost data, the accounting approach, and the econometric analysis of country-year level OECD HC cost data, have limitations. In arriving at our preferred empirical estimates of the role of TC in driving growth in Canadian HC costs, therefore, we consider the apparent quality of the estimates obtained from each approach. If, for instance, there is a large amount of unexplained variation in the regression models of OECD country level HC costs, (i.e. should the R^2 value be low) then these results will be given less weight. Or if

the validation tests of the residual models suggest that there is model misspecification, then the results of these models will be discounted. Finally, in arriving at our preferred set of estimates, we also consider the existing evidence, both domestic and foreign, obtained from a comprehensive search of the literature. These estimates can be used to bound the size of the estimates for Canada. To illustrate, suppose that 45% of the growth in US HC costs is estimated to be due to TC. Because the rate of adoption of new HC technologies in the US appears to be much greater than that in Canada, it follows that the estimate of the impact of TC on Canadian HC costs should be less than 45%.

Results

Recall that we model health care spending, not in real per capita terms, as is common in the literature, but in nominal terms. To assess the contribution of population growth and health care price inflation to growth in nominal HC expenditures, we include these variables as covariates in our regression models. The normalization of expenditures into real per capita terms, which is standard practice in the literature, implicitly assumes that both inflation and population growth have unit health care spending elasticities. If one is prepared to make this assumption, one can estimate the contribution of inflation and population growth on HC expenditures by computing the average annual rate of growth of nominal, per capita and real per capita national health care spending, by health care category over different time periods. The difference in growth rates between the nominal and per capita series reflects the contribution of population size, and the difference in growth rates between the per capita and real per capita series reflects the contribution of price inflation.

Results of this exercise are displayed in Table 2. Growth rates over two different time periods are estimated: the complete data and the last 12 years of the data series, from 1996 to 2008. The latter period corresponds to the period during which provincial governments re-invested in healthcare system after the 6 years of retrenchment. During this expansionary period, national prescription drug spending increased at an average annual rate of about 9.7%. About 1 percentage point of this growth is attributable to population size; inflation was negligible. This means that the majority of the growth in nominal drug expenditures ($8.5/9.7\times100 \approx 88\%$) remains to be explained by population aging, income and other factors. Over the same 12 year period, nominal non-drug expenditures (most of which is spent on inpatient and ambulatory care) increased at an average annual rate of about 6.8%. Again, about 1 percentage point of this 6.8% is attributable to population growth and 2.4 percentage points to inflation, leaving 3.4 percentage points to be explained by other factors. This implies that TC can explain no more than $3.4/6.8\times100 \approx 50\%$ of the growth in nominal non-drug spending over the 12 year period.

Table 2 Estimated average annual rate of growth of nominal, per capita and real per capita national health care spending, by health care category and time period

	Category	**Time Period**	
	Prescription Drugs	1987-2008 (last 21 yrs)	1996-2008 (last 12 yrs)
A	Nominal	9.25%	9.66%
B	Per capita	8.20%	8.68%
C	Real per capita	8.01%	8.54%
A-B	Growth from population size changes	1.05%	0.98%
B-C	Growth from inflation	0.19%	0.14%

	Category	**Time Period**	
	Non-drug expenditure	1975-2008 (last 33 yrs)	1996-2008 (last 12 yrs)
A	Nominal	7.09%	6.76%
B	Per capita	5.98%	5.78%
C	Real per capita	2.63%	3.4%
A-B	Growth from population size changes	1.11%	0.98%
B-C	Growth from inflation	3.35%	2.38%

We next review Figure 1.1, a time series graph of real per capita national spending on the two health care categories considered in this report, prescription drugs and other non-drug (which reflects mostly spending on ambulatory and inpatient care). Several things are noteworthy from the graph. First, non-drug spending is about 5 times as large as drug spending; second, non-drug spending growth slowed in the period 1990-1995, whereas drug spending increased monotonically throughout the entire period; third, starting in about 1996, both series grew at a slightly faster rate that in previous periods. Figure 1.2 presents the same data in nominal per capita terms and Figure 1.3 presents the data in real per capita terms. It is clear from 1.3 that there was an actual decline in real per capita non-drug expenditures over the first half of the 1990s.

One reason for the decline in the growth of non-drug spending is that provincial government health programs finance the majority of this spending. The provincial governments, in turn, finance a large share of their social program spending from federal government transfers; these transfers were curtailed in the early 1990s. Figure 2 illustrates that real per capita provincial government current expenditures declined sharply over the first half of the 1990s whereas real per capita GDP declined earlier, from about 1988-1992. This suggests that provincial government current expenditure is the preferred measure of the resources available to fund healthcare and other social programs.

Figure 1.1 Nominal prescription drug expenditures and nominal non-drug expenditures, 1975-2008, Canada (CAN$ million)

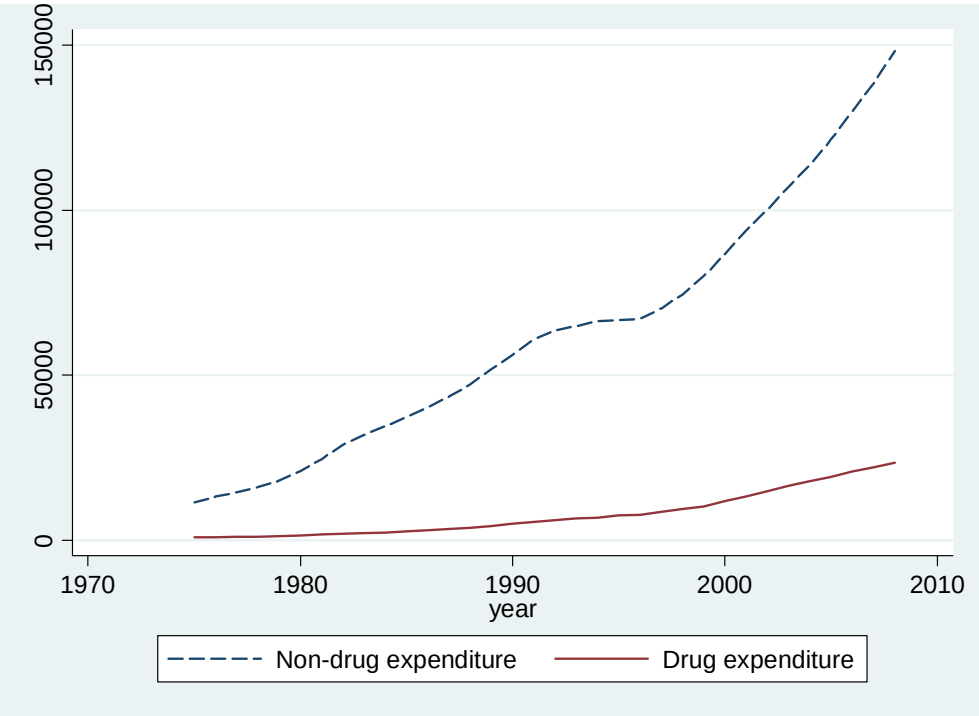


Figure 1.2 Nominal per capita prescription drug expenditures and nominal non-drug expenditures, 1975-2008, Canada (CAN$)

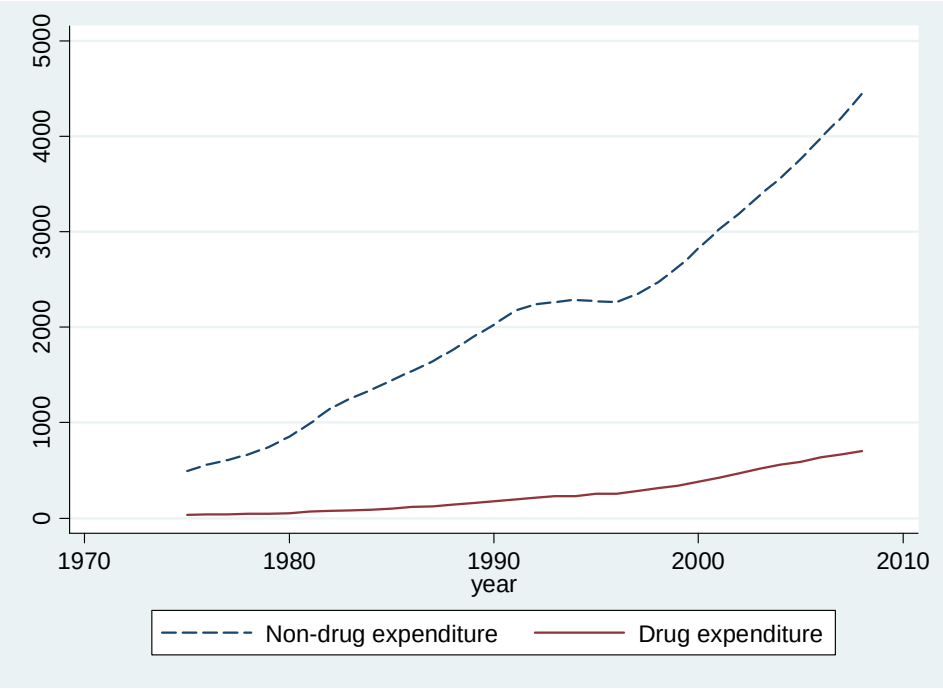


Figure 1.3 Real per capita prescription drug expenditures, 1987-2008, and real per capita non-drug expenditures, 1975-2008, Canada (CAN$)

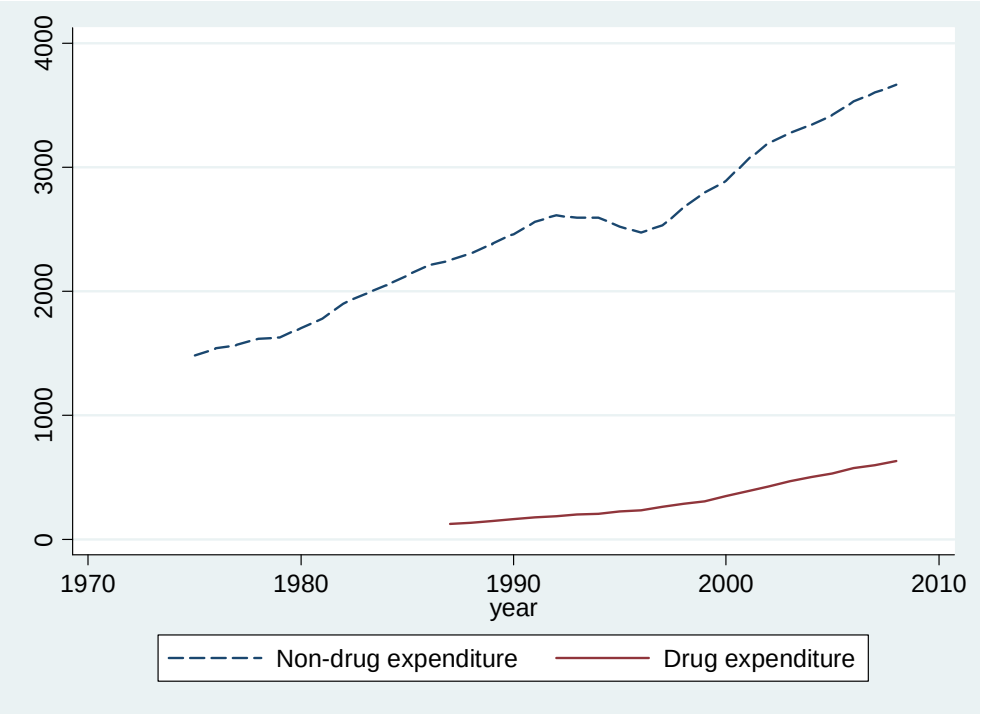
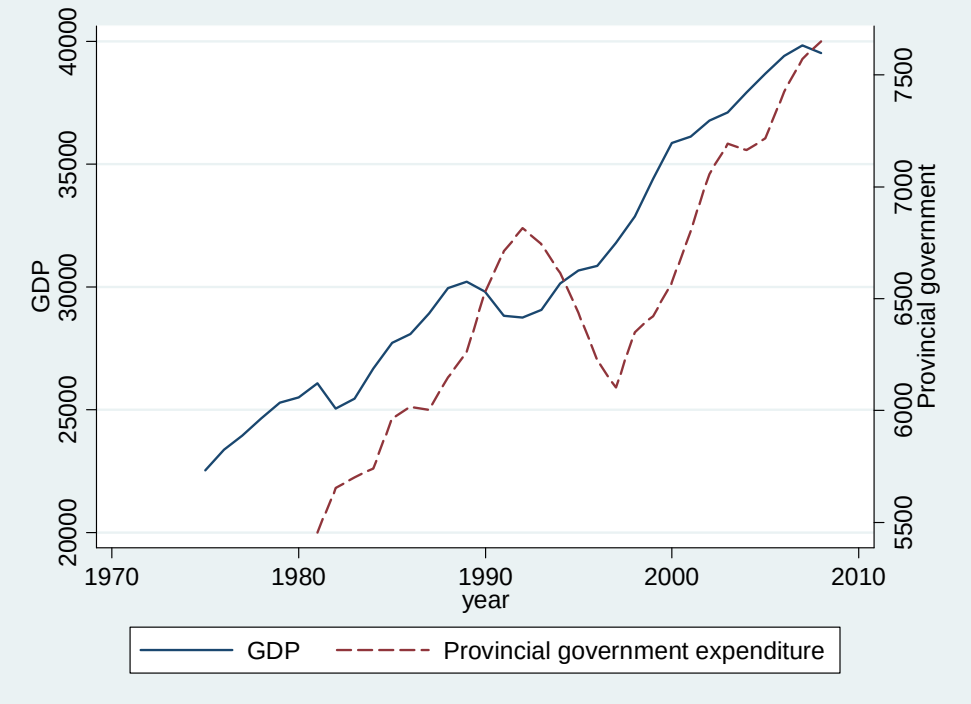


Figure 2. Real per capita GDP and real per capita current provincial government expenditures, Canada.



The direct approach for prescription drug expenditures

We used national data to estimate how TC in the pharmaceutical sector, as measured by the number of new branded drugs approved for use each year, affects growth in prescription drug expenditures.

Expenditure growth is estimated as log y[t] - log y[t-1], where y[t] is prescription drug expenditures in year t, and y[t-1] is prescription drug expenditures in the previous year. The regression model for drug expenditure growth can be expressed as:

$$\log y[t] - \log y[t-1] = \mathbf{x}[t]^T\boldsymbol{\beta} + \varepsilon \qquad \text{equation (2)}$$

where $\mathbf{x}[t]$ is the year t values of a set of covariates, including demographic variables, real government current expenditures, the number of new brand drugs that Health Canada approved in year t, and the number of new generic drugs that Health Canada approved in year t; $\boldsymbol{\beta}$ is a conformable set of parameters that we estimate using ordinary least squares (OLS). ε represents the combined influence of all unmodelled factors that influence the growth rate in drug expenditures.

The regression model described above, equation (2), can be thought of as a special case of a more general model:

$$\log y[t] = \alpha \log y[t-1] + \mathbf{x}[t]^T\boldsymbol{\beta} + \varepsilon \qquad \text{equation (3)}$$

Equation (2) essentially is equation (3) in which the parameter $\alpha=1$. We estimated variants of equation (3), and focused on the estimated impact of the number of new brand drug approvals on drug spending. The eight models, displayed below, variously include or exclude: a) the lagged value of log real per capita national prescription drug expenditure, and b) a linear time trend. The models also either use the (log) number of brand drugs approved or the (log) number of brand drugs approved categorized by their "first in class" status or "follow-on" status. First in class drugs are those that are the first to be approved in a therapeutic category. Follow-on drugs are those that are subsequently approved in a therapeutic category. The idea here is that first in class drugs expand therapeutic options more than follow on drugs and thus may lead to greater expenditure growth than follow on drugs.

Table 3 OLS estimates of regression model of log real per capita national prescription drug expenditure, 1987-2008

Covariates	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Lagged outcome		0.510**		0.428**		0.547***		0.468***
		(0.187)		(0.152)		(0.163)		(0.133)
Time trend	0.0241	-0.0239			0.0329	-0.0258		
	(0.0296)	(0.0310)			(0.0309)	(0.0307)		
Age proportion 0-14	17.46***	11.66***	17.53***	12.54***	17.97***	11.28***	17.92***	12.27***
	(3.773)	(3.891)	(3.740)	(3.681)	(4.079)	(3.875)	(4.091)	(3.666)
Age proportion 65-74	-8.355	1.197	-4.934	-2.636	-6.916	2.740	-1.747	-1.386
	(6.442)	(6.574)	(4.846)	(4.256)	(6.827)	(6.262)	(4.808)	(3.875)
Age proportion 75 plus	65.08**	71.39***	86.53***	55.94***	59.50**	70.81***	88.67***	53.75***
	(27.19)	(23.60)	(6.760)	(12.33)	(28.36)	(23.33)	(7.201)	(11.50)
Log real per capita government expenditure	0.713**	0.0874	0.617**	0.253	0.677**	0.0271	0.530*	0.199
	(0.275)	(0.330)	(0.246)	(0.249)	(0.293)	(0.307)	(0.259)	(0.229)
Log first-in-class approvals	-0.0180	-0.000990	-0.0182	-0.00354				
	(0.0128)	(0.0127)	(0.0127)	(0.0122)				
Log follow-on approvals	0.0275	0.0218	0.0342	0.0183				
	(0.0266)	(0.0230)	(0.0251)	(0.0223)				
Log generic approvals	-0.0347*	-0.0406**	-0.0301	-0.0428**	-0.0438**	-0.0437**	-0.0393*	-0.0461***
	(0.0194)	(0.0169)	(0.0184)	(0.0165)	(0.0198)	(0.0161)	(0.0194)	(0.0157)
Log brand approvals					0.00178	0.0197	0.0124	0.0115
					(0.0325)	(0.0270)	(0.0310)	(0.0250)
Constant	-11.19***	-8.914***	-12.53***	-8.377***	-11.39***	-8.863***	-13.29***	-8.218***
	(2.034)	(1.946)	(1.189)	(1.797)	(2.141)	(1.899)	(1.174)	(1.726)
Observations	28	28	28	28	28	28	28	28
R-squared	0.998	0.998	0.998	0.998	0.997	0.998	0.997	0.998

Note: estimated standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

We find that although there is some evidence that new brand drug approvals increase drug spending growth, and generic drug approvals reduce drug spending growth, the estimates are simply too imprecise to be able to draw any firm conclusions. We therefore rely on other approaches to estimate the effect of TC on drug (and non-drug) spending growth.

Residual models for drug, non-drug and total health care spending

We estimated the parameters of the regression models for prescription drug expenditures, non-drug expenditures and total health care expenditures using province-year level data. The OLS parameter estimates appear in Appendix 1. Recall that the focus of these models are the year effect estimates, which are intended to capture the effect of TC and

other time varying factors that are common to all provinces. The year effect estimates, as well as their estimated 95% confidence intervals, are displayed in the figures below. All health care expenditures are expressed in logarithms, so that the year effects are also expressed in log units. (We formally tested that the log transform was most compatible with the data using likelihood ratio tests. Results of these tests, presented in Appendix 2, overwhelming support the log transform.) A convenient feature of log models is that the estimated expenditure growth due to TC can be obtained by taking the difference in year effect estimates. Thus if the year effect estimate for 2008 is 0.3 and the year effect estimate for 1996 is 0.2, then the growth in spending between 1996 and 2008 is approximately equal to 0.3 – 0.2 = 0.10, or 10 percentage points.

Total health care expenditure

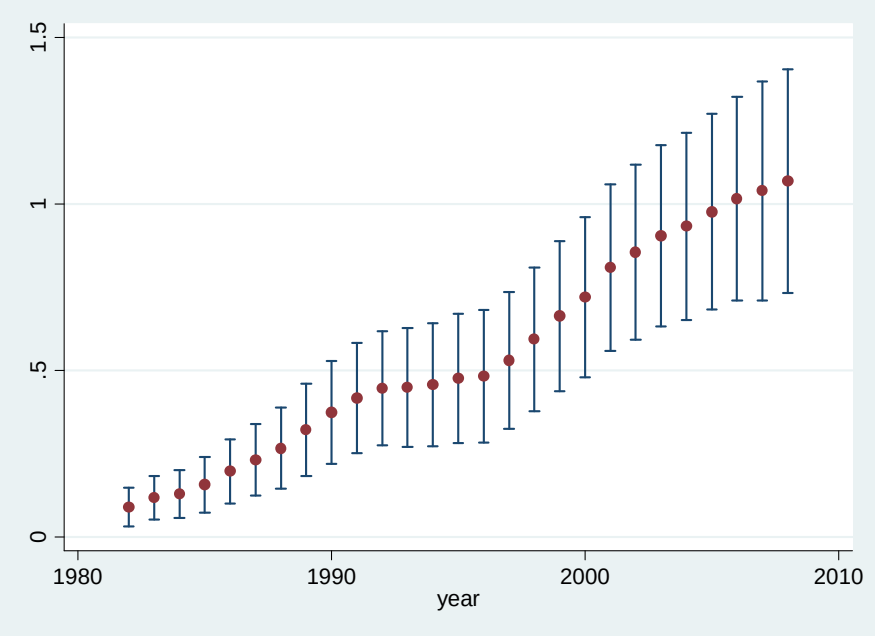
We turn first to the results of the total healthcare expenditure models, which are displayed in Figures 3 (baseline model), 4 (augmented model) and 5 (validation model). The estimated year effects in the baseline models decline in the early 1990s, the period of program retrenchment. This suggests that the use of the covariate measuring total provincial government program spending is not completely capturing the effects of reduced health care program expenditures. This feature remains even with the inclusion of measures of health care capacity in the augmented model.

The use of the proxy measures of TC – the number of CT and MRI scanners in operation – does provide some indication that the year effects are indeed capturing the effects of TC. This is clear from the fact that the year effects decline in magnitude after these imaging variables are included in the regression.

Table 4. List of variables used in regression models of category-specific nominal health expenditure (total, prescription drug and non-drug)

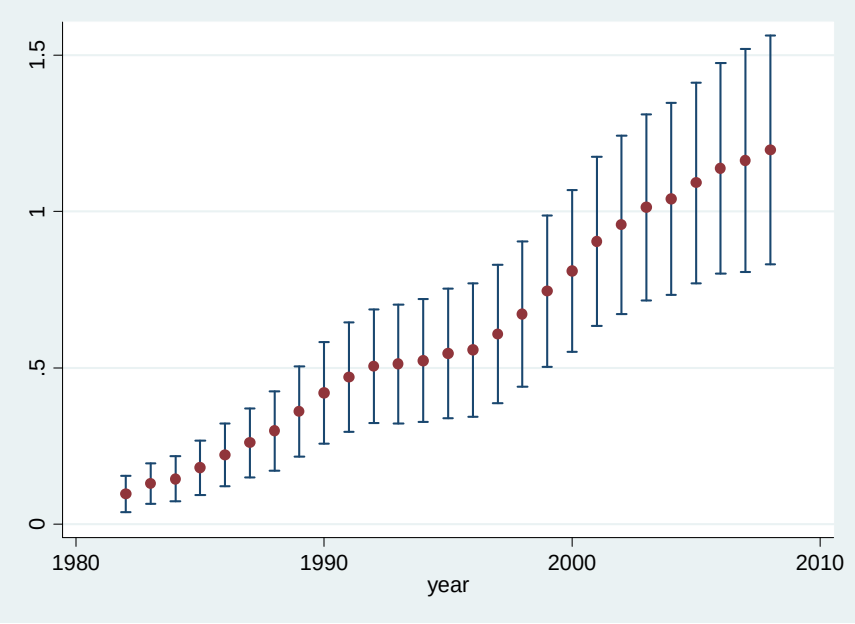
Explanatory variables	Baseline models	Augmented models	Validation models
Log provincial government current expenditure	▯	▯	▯
Log personal current expenditure	▯	▯	▯
Log total population	▯	▯	▯
Log population 0-4 years	▯	▯	▯
Log population 5-19 years	▯	▯	▯
Log population 45-64 years	▯	▯	▯
Log population 75+ years	▯	▯	▯
Government Current Expenditure Implicit Price Index (total + non-drug models)	▯	▯	▯
Patented Medicine Price Index (prescription drug model)	▯	▯	▯
Province dummies	▯	▯	▯
Year dummies (to capture the influence of technological change)	▯	▯	▯
Number of Specialists		▯	▯
Number of Family Doctors		▯	▯
Number of CT scanners			▯
Number of MRIs			▯

Figure 3. Year effect estimates from the baseline total healthcare expenditure model



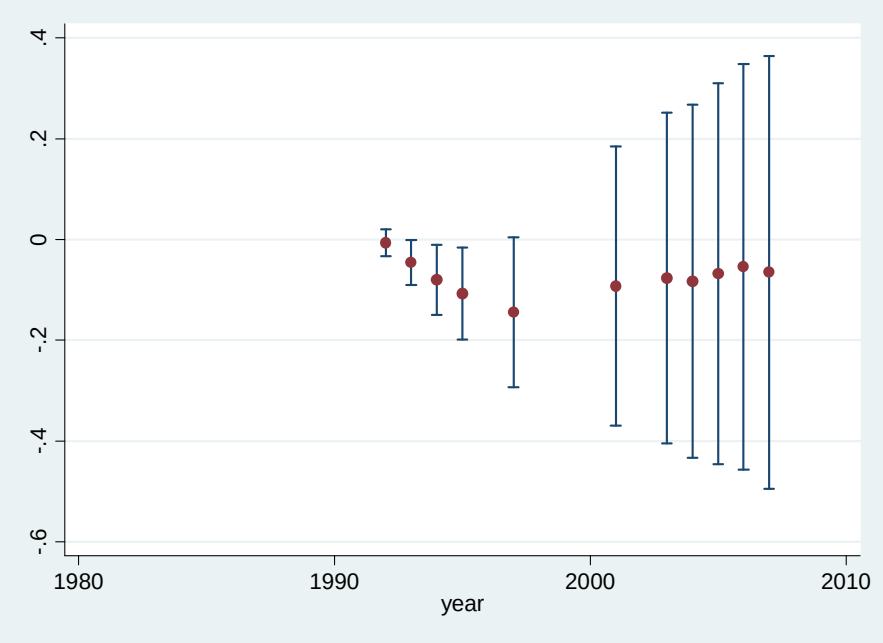
Note: Year effect estimates and their 95% confidence intervals from the baseline model of log total health expenditure on demographics, population size, personal expenditure and government expenditure on goods and services, the government expenditure on goods and services price deflator and province fixed effects.

Figure 4. Year effect estimates from the augmented total healthcare expenditure model



Note: Year effects from the model of log total health expenditure that include covariates from the baseline model plus healthcare capacity variables (the number of primary care physicians and specialist physicians)

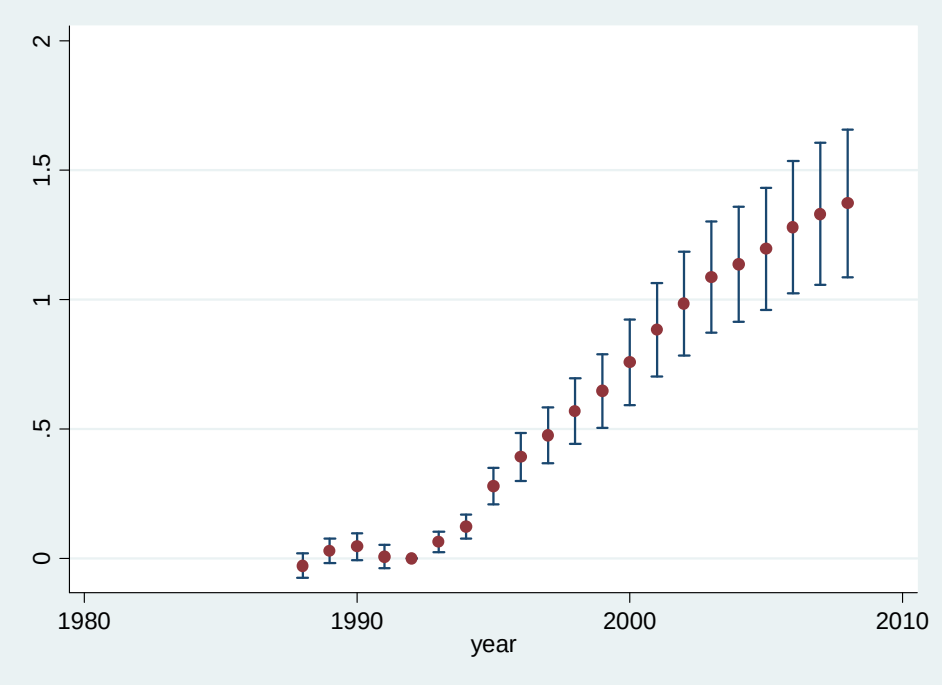
Figure 5. Year effect estimates from the total healthcare expenditure validation model



Note: Year effects from the model of log total health expenditure that include covariates from the augmented model plus the number of imaging devices. Note that data on the number of imaging devices is limited to the period 1993-2008.

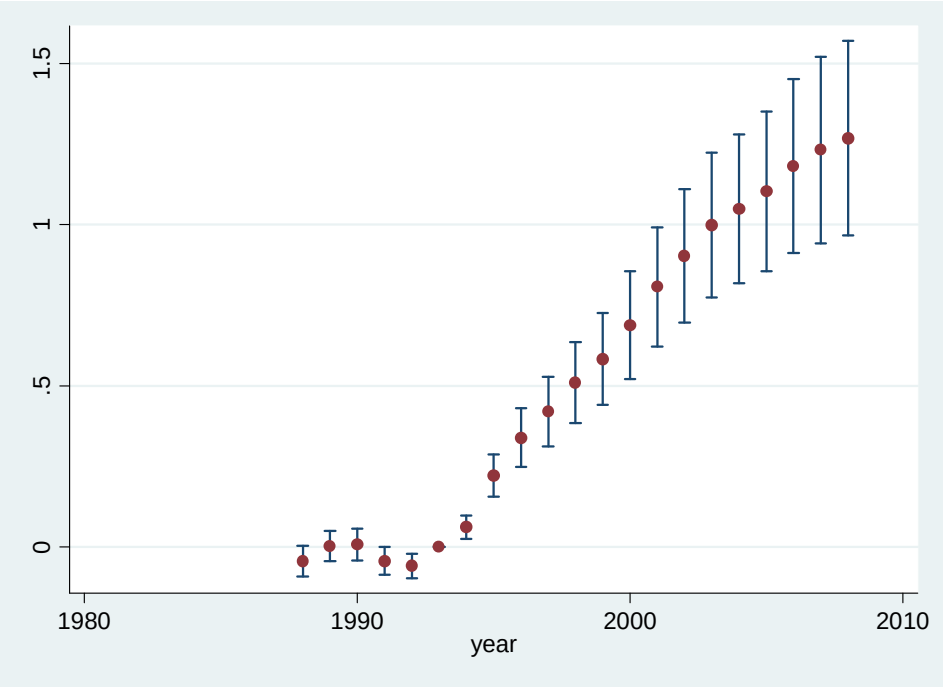
We next turn to the year effect estimates from the models of log prescription drug expenditure. The baseline model is displayed in Figure 6, and the augmented model is displayed in Figure 7. The first finding is that there was a rapid increase in drug expenditures growth after 1995. Second, we note that the baseline and augmented year effect estimates are quite similar, suggesting that the inclusion of the HC capacity variables – the number of primary care physicians and specialist physicians – had little impact on drug costs. This is confirmed by inspection of the regression model estimates in Appendix 1.

Figure 6. Year effect estimates from the baseline prescription drug expenditure model



Note: Year effect estimates and their 95% confidence intervals from the baseline model of log prescription drug expenditure on demographics, population size, personal expenditure and government expenditure on goods and services, the patented medicines price index and province fixed effects.

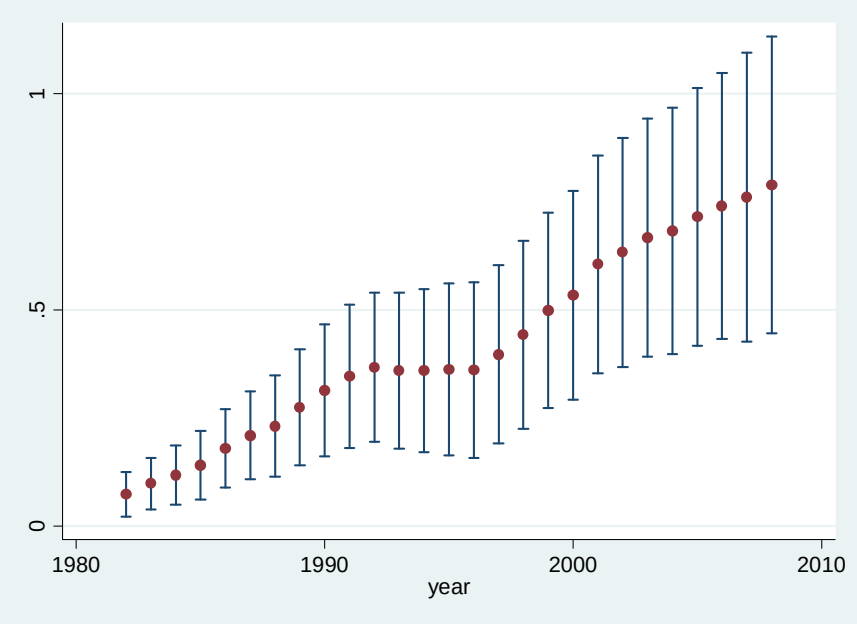
Figure 7. Year effect estimates from the augmented prescription drug expenditure model



Note: Year effects from the model of log prescription drug expenditure that include covariates from the baseline model plus the number of primary care physicians and specialist physicians.

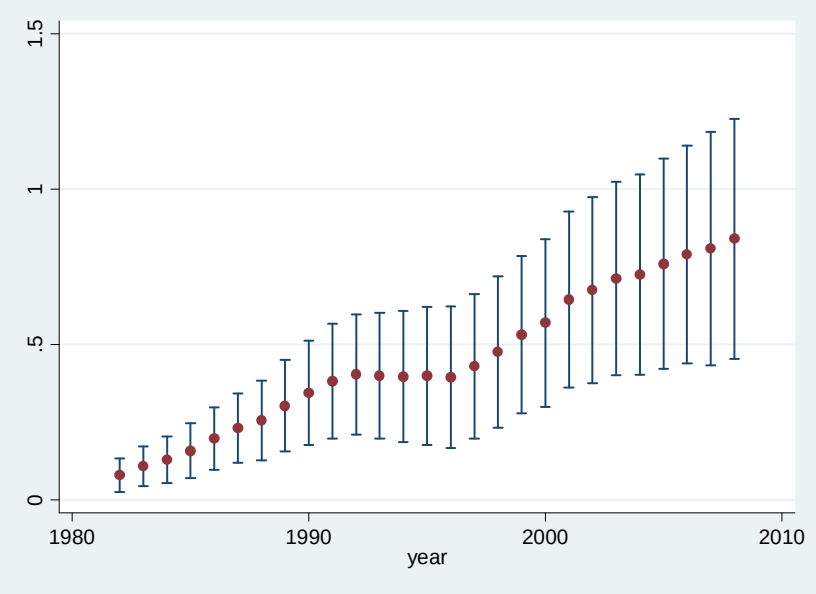
Finally, we turn to the year effect estimates from the models of log non-drug expenditure. The baseline model is displayed in Figure 8, the augmented model in Figure 9 and the validation model in Figure 10. The first finding is that the effects of the retrenchment in provincial government ambulatory and inpatient health care program spending are apparent in both the baseline and augmented year effect estimates. Again, this suggests the year effects are picking up effects of this retrenchment that are not captured by provincial government expenditures and HC capacity variables – the number of primary care physicians and specialist physicians. This reflects a defect of the residual based approach, namely that it will pick up the effects of *all* time varying factors not explicitly modeled. That being said, the effects of this retrenchment likely do not extend to the analysis period, 1996 to 2008, as the retrenchment was over by 1996. Moreover, the validation model year effect estimates decline, suggesting (somewhat reassuringly) that the number of available imaging devices, our proxy for the level of health technology, is included in the year effects in the augment and baseline models.

Figure 8. Year effect estimates from the baseline non-drug expenditure model



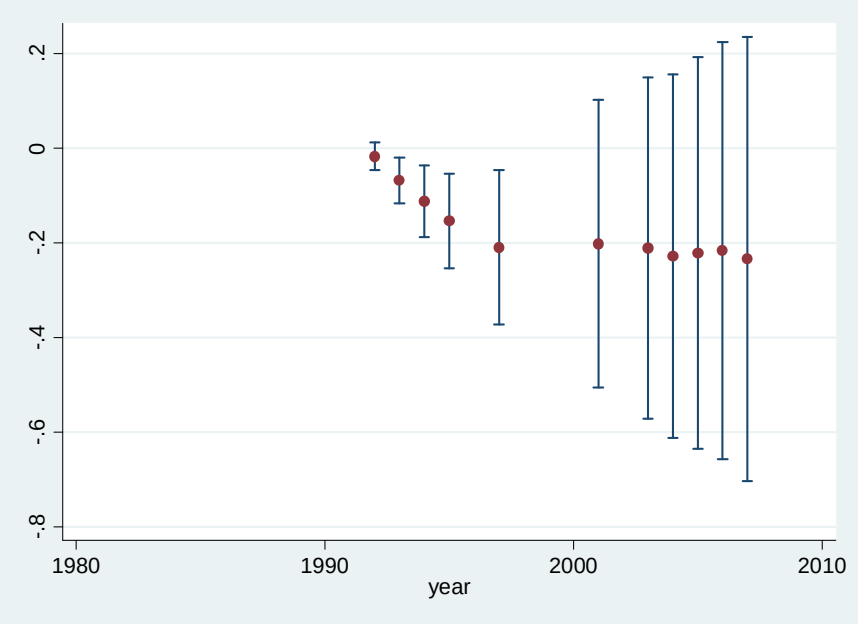
Note: Year effect estimates and their 95% confidence intervals from the baseline model of log non-drug expenditure on demographics, population size, personal expenditure and government expenditure on goods and services, the government expenditure on goods and services price deflator and province fixed effects.

Figure 9. Year effect estimates from the augmented non-drug expenditure model



Note: Year effects from the model of log non-drug expenditure that include covariates from the baseline model plus the number of primary care physicians and specialist physicians.

Figure 10. Year effect estimates from the non-drug expenditure validation model



Note: Year effects from the model of log non-drug expenditure that include covariates from the augmented model plus the number of imaging devices. Note that data on the number of imaging devices is limited to the period 1993-2008.

We now use the year effect estimates to estimate the contribution of TC to the growth in drug and non-drug expenditures over the period 1996-2008. These are obtained by computing the difference in the year effect estimates for these two years and dividing this by the growth in the nominal expenditures over the same period. Results are displayed in Table 4. We find that TC explains about 45% of the growth of nominal prescription drug expenditures over this period; TC explains about 37% of the growth of nominal non-drug expenditures over this period.

We can express these estimates in terms of the average annual growth rate in health care spending due to TC. Recall from Table 2 that the average annual growth in rate in nominal prescription drug expenditures over the period 1996-2008 was 9.66%. Our estimates suggest that TC is responsible for 45% of this growth. In other words, TC is responsible for about .45×9.66 =4.35 percentage points of the average annual growth rate in nominal prescription drug expenditures over the period 1996-2008.

Recall as well from Table 2 that the average annual growth in rate in nominal non-drug expenditures over the period 1996-2008 was 6.76%. Our estimates suggest that TC is responsible for 37% of this growth. In other words, TC is responsible for about .37×6.76 =2.50 percentage points of the average annual growth rate in nominal non-drug expenditures over the period 1996-2008.

Table 5 Residual regression model estimates of the contribution of technological change on growth in a) nominal prescription drug expenditure and b) nominal non-drug expenditure over the period 1996-2008

PRES. DRUG EXPENDITURE AUGMENTED MODEL			
Year	year effects	Pres. drug expenditure (in $million)	% contribution of technology to pres. drug expend.
1996	0.339	7,602.1	
2008	1.269	23,445.0	
% change between 1996-2008	93%	208.4%	44.6%

NON-DRUG EXPENDITURE AUGMENTED MODEL			
Year	year effects	non-drug expenditure (in $million)	% contribution of technology to non-drug expend.
1996	0.395	67,117.0	
2008	0.841	148,331.8	
% change between 1996-2008	44.6%	121%	36.9%

Note that the year effect estimates are derived from the estimated augmented models, which are displayed in Appendix 1. We use the difference in year effects to approximate the percentage change in expenditures due to technological change. 95% confidence intervals for the difference between the 1996 and 2008 year effects are as follows. For drug expenditures model: Difference = 0.93, with 95% CI = (0.70 - 1.15). For non-drug expenditures model: Difference = 0.45, with 95% CI = (0.275 - 0.616).

The estimates presented above also can be used to estimate the growth in nominal drug and non-drug expenditures over the period 1996 to 2008 due to TC. To do so, we applied the estimated average annual growth rate (AAGR) in health care expenditures due to TC to the base year (1996) level of healthcare spending. Thus, if 1996 healthcare spending is $1 billion and the AAGR in health care spending due to TC is 3% then we would estimate that the adoption of new health technologies resulted in a $30 million increase in healthcare spending by 1997, ($30 m = $1 bn * 1.03 - $1 bn). After two years, the adoption of new health technologies results in a cumulative increase in healthcare spending of 1.03^2 - $1 bn = 61 million, etc.

We conducted this procedure for both prescription drug and non-drug expenditures and total health care expenditures. Results are reported in Table 6.

Table 6. Estimated growth in nominal prescription drug, non-drug and total health care expenditures over the period 1996-2008 due to technological change

year	cumulative increase in drug expend due to technological change ($ mil)	cumulative increase in non-drug expend due to technological change ($mil)	cumulative increase in total healthcare expend due to technological change ($mil)
1997	327.53	1,671.92	1,999.45
1998	669.17	3,385.50	4,054.66
1999	1,025.52	5,141.75	6,167.28
2000	1,397.23	6,941.76	8,338.99
2001	1,784.96	8,786.61	10,571.57
2002	2,189.39	10,677.41	12,866.80
2003	2,611.24	12,615.32	15,226.56
2004	3,051.27	14,601.49	17,652.76
2005	3,510.26	16,637.15	20,147.41
2006	3,989.02	18,723.51	22,712.53
2007	4,488.41	20,861.85	25,350.26
2008	5,009.31	23,053.46	28,062.77

Note: the estimated average annual growth rate (AAGR) in prescription drug spending over the period 1996-2008 due to technological change is 4.31%. Nominal spending on prescription drugs in 1996 is $7,602.13 million. The estimated AAGR in non-drug spending over the period 1996-2008 due to technological change is 2.49%. Nominal non-drug spending in 1996 is $67,116.95 million.

As is evident from the results presented in the table, total spending on health care technology grew by approximately $28 billion over the period 1996-2008. Of this, the majority ($23 billion) was due to spending on non-drug technologies; this would include the construction of new hospitals, the acquisition and operation of new diagnostic imaging devices, and payments to healthcare providers who deliver new health services.

The remaining $5 billion expenditure growth represented spending on new prescription drugs.

Validation of the regression-based residual approach

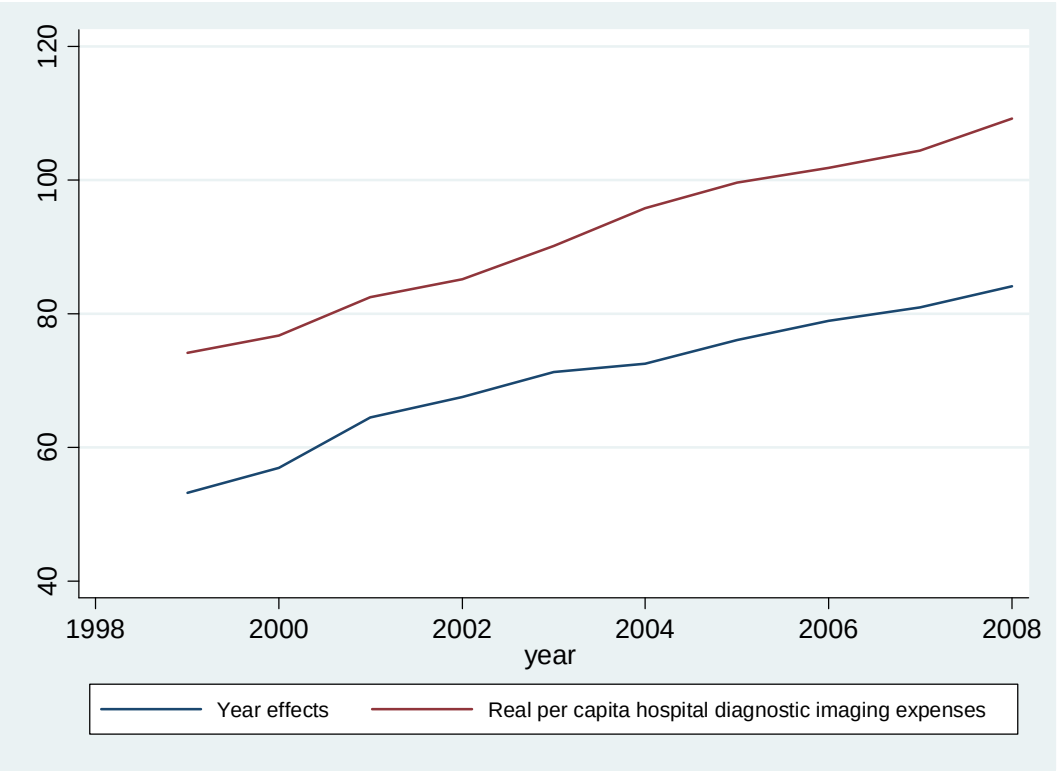
Recall that data limitations prevented us from estimating the level of spending on technology (and hence we were unable to directly model the effect of TC on HC costs). We do, however, have some information on spending on a subset of health technology, namely spending on MRI, CT scans and other hospital-based diagnostic services. Recall that hospital spending is a significant share of the non-drug category. Moreover, outlays on diagnostic imaging likely mirror spending on other components of health technology. As a check on our regression models, we compared the growth in the estimated fixed effects obtained from the augmented non-drug regression model with the growth in spending on hospital based diagnostic services. Ideally these would be highly correlated.

The data indicate that there have been substantial investments in diagnostic technologies over the first decade of 2000. We know from CIHI's Medical Imaging Technology Database that between 2003 and 2010, the number of CT and MRI scanners installed and put into operation in Canadian hospitals increased from 10.0 to 13.5 per million population and from 3.9 to 6.3 per million population, respectively. The number of yearly exams performed also increased over the time period. In 2003, 87 CT exams per thousand population and 24 MRI exams per thousand population were performed. In 2009 rates of use were 124 CT exams per thousand population and 43 MRI exams per thousand population. The number of CT and MRI exams performed yearly has increased at a higher pace than the number of scanners, reflecting increasing intensity of utilization.

Canadian hospitals (except those based in Québec) report their diagnostic operating expenses by type of medical imaging equipment to CIHI, which is assembled in CIHI's Canadian MIS Database (CMDB).[6] According to the CMDB, Canadian hospital spending on diagnostic imaging increased from $1,315 million in 1999-00 to $2,794 million in 2008-09. This rate of increase mimics the rate of growth of the technology-related non-drug spending. We graphed real per capita spending on diagnostic imaging and the year effects from the augmented non-drug regression in Figure 11. The two series are highly correlated (r=.986), providing some validation of our non-drug residual model.

[6] The Canadian MIS Database (CMDB) contains financial and statistical information from hospitals and limited data from health regions across Canada. The day-to-day operations of health service organizations is collected according to a standardized framework based on a standardized chart of accounts, general accounting policies and procedures, workload measurement systems, service activity statistics and indicators that support management decision-making in health service organizations. The framework is known as the Standards for Management Information Systems in Canadian Health Service Organizations (MIS Standards).

Figure 11. Year effect estimates and Canadian hospital diagnostic imaging expenditures 1999-2008



Note: Year effects from the non-drug augmented regression are multiplied by 100 to have a scale similar to per capita hospital diagnostic imaging expenses.

The accounting-based residual approach

We next turn to our estimation of the role of TC on the growth in health care costs using the accounting-based residual approach. Recall that this requires us to 1) measure the growth in cost drivers over this period, 2) obtain from the literature estimates of the impact that these cost drivers have on health care costs (these estimates are typically expressed as elasticities); 3) find the component of the observed growth in health care costs that is attributable to these cost drivers (as per the formula in equation 1), and 4) compute the residual growth in health care costs.

We note that the elasticities in the literature are available only for total health care costs, not for its subcomponents, so that we can perform this exercise for total health care costs (drug + non-drug) only.

The cost drivers considered in the literature include income, demographic changes (i.e. changes in the age-sex composition of the population), and in some papers, medical price inflation over and above general economy wide inflation. We address each of these in turn.

First, for the role of income, we estimated the change for real per capita income for Canada for the period 1996-2008 to be 28.1%. As to the income elasticity, there is a range of possible values and they vary across countries. For the US, Cutler (1995) used 0.2, while Smith et al (2009) used 0.6-0.9. For European countries, it is estimated to be 0.65-0.68 (see Dybczak and Przywara, 2010)). For Canada, the income elasticity is estimated to be 0.88 (see Ariste and Carr, 2002) and is assumed to be 1 by Dodge and Dion (2011).

The low elasticity (i.e. 0.2) used in Cutler (1995) reflects the typical magnitude of income elasticities obtained from micro-data studies, while larger income elasticities (i.e. 1 or higher) are normally obtained from macro cross-country studies. A recent US study (Smith et al. 2009) favored using the income elasticity from macro studies because the low income elasticity from micro-level studies only reflects the effect at the level of households who directly spend only a fraction of their budgets on healthcare. Meanwhile, as a single payer system, the Canadian income elasticity is unlikely to be as high as in the US. Therefore, in our calculations, we assumed an income elasticity of between 0.5-0.8. Multiplying the income elasticity (0.8) with the change in income (i.e. 28.1%) gives us 22.5%, which is the percentage increase in health expenditure that can be attributed to rising income.

Real per capita health expenditures were estimated to have grown by 54.1% over the 12 year period 1996-2008. (This figure uses the government current expenditure implicit price index to deflate spending into real terms.) We can thus infer that rising income during the period 1993-2008 accounts for 22.5/54.1=41.6% of the observed increase in real per capita health expenditure.

If the income elasticity is 0.5, then rising income contributes 0.5×28.1%=14.1 percentage points to the total change in real per capita health expenditure (i.e. 14.1/54.1=26% of the observed increase in real per capita health expenditure).

To account for the contribution of demographic changes, we used direct standardization. Specifically, we first estimated the change in the age proportions of the population (the changes in age proportions for age groups, 0-4, 5-19, 20-44, 45-64, 65-74 and 75 plus) between 1996 and 2008. We then multiplied these age specific changes with the age specific health care costs from a base year (2007). The results indicate that demographic changes (also referred to as "population aging") during 1996-2008 contributed an increase of 10.07% in real per capita health expenditure (or equivalently, 10.07/54.1=18.6% of the observed increase in real per capita health expenditure).

Two prominent papers in the literature – Cutler (1995) and Dodge and Dion (2011) – also account for medical inflation that is in excess of the economy-wide rate of inflation. Dodge and Dion (2011) account for the sources of growth in real per capita health care expenditures in Canada over the period 1996-2009. Economy wide inflation is taken to be the GDP deflator and the medical price inflation is measured using the National Accounts price of health service consumption, which they describe as "a value-added deflator that is essentially driven by the evolution of wages and salaries in the healthcare sector and drug prices." If we were to follow the methods used by Dodge and Dion, we run the risk of over-estimating the role of inflation given that our price deflator is the

provincial government current expenditure implicit price index, which will be heavily weighted by wages in the health care sector.

Dodge and Dion (2011) use an excess average rate of medical inflation of 0.65% per annum during the period 1996-2009. This inflation rate would increase medical prices by 8.79% over the period 1996-2008. If we use an elasticity of health care spending with respect to medical prices of 0.8, (which is 1-0.2, where the 0.2 is the price elasticity of health care demand used by Cutler (1995)), then that means that excess medical inflation is responsible for an increase of 8.79%×0.8=7.03% in real per capita health expenditure over the period 1996-2008. That is, excess medical inflation contributes 7.03/54.1 = 13% of the observed increase in real per capita health expenditure over this period.

If we were to combine the estimates of the contributions of (i) income, (ii) demographic changes and, (ii) excess medical inflation, we infer the size of the residual to be:

i) 100 - (41.6 + 18.6 + 13) = 26.8% (if income elasticity = 0.8)

ii) 100 - (26 + 18.6 + 13) = 42.4% (if income elasticity = 0.5)

If we were to downweight the role of excess medical price inflation (given the concerns we raised earlier) to half of the above value then the residual contribution would increase to:

iii) 100 - (41.6 + 18.6 + 6.5) = 33.3% (if income elasticity = 0.8)

iv) 100 - (26 + 18.6 + 6.5) = 48.9% (if income elasticity = 0.5)

The regression-based residual approach using OECD data

We noted in the methods section several limitations with the OECD data. Unfortunately, the OECD data are limited by yet another feature that we were not aware of at the time of writing of our interim report: widespread missing data for many of the G7 countries (including France, the UK, Germany and other countries that were roughly comparable to Canada in terms of level of economic development). As a result, we were simply unable to get reliable estimates of the country-specific linear time trends and thus had to rely on the CIHI NHEX data for the estimation of our econometric models.

Synthesis of different estimates

We are now in a position to synthesize the evidence. We first note that there is very good evidence that our estimates of the fraction of total HC costs that is attributable to TC can be no greater than 50%. The reason is that, from our review of the literature, 50% appears to be a common estimate for the US health system, which we believe to be more technology intensive than Canada's health care system. The estimates that we derived from our regression-based and accounting-based residual models support this conclusion. Our regression-based models suggest that

- TC is responsible for about 45% of the 9.66% average annual growth rate in nominal prescription drug expenditures over the period 1996-2008.

- TC is responsible for about 37% of the 6.76% average annual growth rate in nominal non-drug (comprised primarily of ambulatory + inpatient service) expenditures over the period 1996-2008.

Given that non-drug expenditures represented a 90% share of total (drug + non-drug) expenditures in 1996, suggests that the overall contribution of TC to total nominal HC costs is approximately 0.90×37% + 0.10×45% = 38% over the period 1996-2008.

This estimate is similar in magnitude to 36%, which is the APC (2005) estimate of the percentage of HC expenditure growth in Australia over the period 1992-93 to 2002-03 that is attributable to TC. It is also similar in magnitude to 35%, which is Di Matteo's (2005) estimate of the percentage of HC expenditure growth in Canada over the period 1975-2000 that is attributable to TC.

Our accounting based residual models suggest that TC explains between 27 – 49% of total real per capita HC costs over the period 1996-2008, depending on the income elasticity used and ones assumptions regarding the level of excess medical price inflation.

Our 38% estimate is at the midpoint of the range of the estimates from the accounting based residual models. Thus our point estimate is 38% and our interval estimate, which reflects the lower and upper bounds on the point estimate, is 27 – 49%. This interval estimate reflects the indeterminacy of the residual (i.e. it reflects the combined effect of TC and other unmeasured trending factors). We are unable to provide similar ranges for the role of TC in the drug and non-drug sectors separately, as we could rely on estimates from just the regression-based model. We do note, however, that our estimate of the ole of TC in the drug sector (45%) is consistent with the literature we review, in particular the 2002 PMPRB report on the share of public drug plan cost growth attributable to new drug launches.

Policy Implications

Several implications for policy makers follow from these results.

First, these results confirm that TC is responsible for a large share -- 45% -- of the growth in prescription drug spending in Canada over the period 1996-2008. This implies that efforts to assess the value for money spent on prescription drugs ("pharmacoeconomics") is likely warranted. That being said, we do note that recently prescription drug spending has slowed and indeed, spending on patented prescription drugs actually declined between 2009 and 2010 (PMPRB 2011). Cutler (2007) and other commentators have noted that the era of the "blockbuster drug" has passed. This should herald a period of new drug introductions with smaller potential revenue potential.

Second, although TC is responsible for a smaller share -- 37% -- of the recent non-drug spending growth, the baseline expenditure on this category of health care is much larger than for prescription drugs, so that the absolute increase in technology related spending over recent years in this category is over four times as large as that for prescription drugs. This implies that assessment of the value for money spent in this sector is likely even more pertinent than pharmacoeconomic assessments.

Assessment of value for money spent on non-drug technologies requires an enormous investment in qualified personnel, given that the technologies are so many and so varied. We note that the Ontario Ministry of Health has provided multi-year funding to an academic research group called the Toronto Health Economics and Technology Assessment (THETA) Collaborative[7] to carry out such studies. Perhaps a national technology assessment body, modeled along the lines of the CADTH would be warranted to handle the large volume of work required to evaluate these technologies.

It would also be useful if a national body such as CIHI routinely collected data on spending on new health care technologies. This need not involve the collection of any new data. For instance, CIHI already collects information on hospital separations in its Discharge Abstract Database. These data include information on procedures performed in hospital. CIHI could track the introduction of new procedure codes (and the retirement of procedure codes displaced by the new procedures) and assess net national level spending on the new procedures. This information could help prioritize the technologies that are subject to economic appraisal. A similar exercise could be performed on the physician billings data, at least for physicians paid a fee for service. The fee schedule could be monitored for year over year changes and spending on newly created fee codes could be tracked.

Finally, we note that some technologies can be cost reducing; a good example is the introduction of cimetidine (Tagamet), a pharmaceutical drug that reduces stomach acid production and reduced the use of more costly gastric surgery. Other technologies can be cost increasing, such as those that manage but do not cure a health problem for which there was previously no treatment. The example of donepezil (Aricept), a drug that treats the symptoms of dementia, comes to mind. It is possible that the net effect of TC is to reduce HC costs. However, virtually every study of the effect of TC on aggregate HC costs finds the opposite to be true. This reflects the fact that the overwhelming majority of new healthcare technologies improve quality at a cost. Fuchs (2010) proposes that there be incentives for the development of technologies that achieve the same quality at lower cost. He writes:

"An additional important result of a value-conscious environment would be the encouragement of innovations whose main effect is to substantially decrease cost while holding quality constant or reducing it only slightly. Such innovations are common in other industries but rare in medicine. If some of the resources devoted to marginal advances in the quality of care were reallocated to the development of innovations that reduced the cost of care, the problem of paying for high-value advances in quality for the entire population would be much easier to address."

[7] http://theta.utoronto.ca/

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Appendix 1: Estimated residual-based regression models for drug, non-drug and total health care expenditures

Table A1. Baseline models of nominal health expenditure

Covariates	Total	Pres. drug	Non-drug
Log Age0_4	0.287***	0.639***	0.0797
	(0.0857)	(0.134)	(0.0789)
Log Age5_19	-0.591***	0.805***	-0.512***
	(0.133)	(0.267)	(0.128)
Log Age45_64	-0.241*	0.492	-0.118
	(0.131)	(0.306)	(0.129)
Log Age75plus	-0.241***	0.470***	-0.331***
	(0.0844)	(0.119)	(0.0812)
Log Population	1.306***	-1.632**	1.334***
	(0.399)	(0.687)	(0.392)
Log personal_expend	0.272	-0.173	0.255
	(0.180)	(0.189)	(0.205)
Log govern expend	-0.00210	0.139	0.0921
	(0.0692)	(0.0888)	(0.0695)
Government implicit price index	0.00629*		0.00775*
	(0.00328)		(0.00412)
PMPI		0.0324***	
		(0.00352)	
P.E.I	-0.239***	-0.576***	-0.160**
	(0.0771)	(0.114)	(0.0791)
Nova Scotia	0.0977*	0.125**	0.134**
	(0.0532)	(0.0596)	(0.0540)
Newbrunswick	0.0779***	0.0597	0.129***
	(0.0292)	(0.0373)	(0.0302)
Quebec	0.457***	0.739***	0.475***
	(0.163)	(0.204)	(0.169)
Ontario	0.616***	0.866***	0.667***
	(0.205)	(0.237)	(0.216)
Manitoba	0.234***	-0.186**	0.357***
	(0.0725)	(0.0749)	(0.0769)
Saskatchewan	0.182***	-0.221***	0.314***
	(0.0673)	(0.0774)	(0.0703)
Alberta	0.231	0.286**	0.329**
	(0.143)	(0.136)	(0.158)
British Columbia	0.395***	0.284*	0.486***
	(0.143)	(0.160)	(0.155)
Year_1982	0.0895***		0.0735***
	(0.0295)		(0.0265)
Year_1983	0.118***		0.0983***
	(0.0331)		(0.0304)
Year_1984	0.129***		0.118***

Covariates	Total	Pres. drug	Non-drug
	(0.0363)		(0.0352)
Year_1985	0.157***		0.140***
	(0.0426)		(0.0406)
Year_1986	0.197***		0.179***
	(0.0494)		(0.0464)
Year_1987	0.232***		0.209***
	(0.0545)		(0.0517)
Year_1988	0.267***	-0.0280	0.231***
	(0.0622)	(0.0241)	(0.0596)
Year_1989	0.322***	0.0287	0.275***
	(0.0708)	(0.0242)	(0.0684)
Year_1990	0.374***	0.0453*	0.314***
	(0.0792)	(0.0261)	(0.0778)
Year_1991	0.417***	0.00702	0.346***
	(0.0845)	(0.0228)	(0.0846)
Year_1992	0.447***		0.367***
	(0.0874)		(0.0882)
Year_1993	0.449***	0.0634***	0.360***
	(0.0908)	(0.0202)	(0.0919)
Year_1994	0.457***	0.123***	0.360***
	(0.0942)	(0.0236)	(0.0962)
Year_1995	0.476***	0.279***	0.362***
	(0.0991)	(0.0357)	(0.101)
Year_1996	0.483***	0.392***	0.360***
	(0.102)	(0.0475)	(0.104)
Year_1997	0.530***	0.476***	0.397***
	(0.105)	(0.0555)	(0.105)
Year_1998	0.594***	0.569***	0.442***
	(0.110)	(0.0647)	(0.111)
Year_1999	0.663***	0.647***	0.499***
	(0.115)	(0.0726)	(0.115)
Year_2000	0.720***	0.759***	0.533***
	(0.123)	(0.0842)	(0.123)
Year_2001	0.809***	0.883***	0.605***
	(0.128)	(0.0923)	(0.128)
Year_2002	0.855***	0.985***	0.633***
	(0.134)	(0.102)	(0.135)
Year_2003	0.905***	1.087***	0.667***
	(0.139)	(0.109)	(0.140)
Year_2004	0.933***	1.137***	0.683***
	(0.144)	(0.114)	(0.145)
Year_2005	0.977***	1.196***	0.715***
	(0.150)	(0.120)	(0.152)
Year_2006	1.016***	1.280***	0.740***
	(0.156)	(0.131)	(0.157)
Year_2007	1.040***	1.332***	0.761***
	(0.168)	(0.140)	(0.171)
Year_2008	1.068***	1.372***	0.789***

Covariates	Total	Pres. drug	Non-drug
	(0.171)	(0.146)	(0.175)
Constant	-4.373***	-3.544*	-4.804***
	(1.129)	(1.937)	(1.095)
Observations	280	220	280
R-squared	0.999	0.999	0.999

Notes: PMPI: Patented Medicines Price Index, Omitted earliest year = 1981 for total health expenditure and for nondrug expenditure regressions, due to government expenditure measures being un available before 1980; Omitted year = 1987 for drug expenditure regression due to PMPI data starting only from 1987; Nondrug expenditure = total health expenditure - prescription drug expenditure; Estimated standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table A2. Augmented models of nominal health expenditure

Covariates	Total	Pres. drug	Non-drug
Log family physician	0.00678	0.0475	-0.0712*
	(0.0453)	(0.0722)	(0.0429)
Log specialist	0.126**	-0.0806	0.0842*
	(0.0490)	(0.0777)	(0.0502)
Log personal_expend	0.284	-0.121	0.301
	(0.175)	(0.195)	(0.207)
Log govern expend	0.00688	0.160*	0.0955
	(0.0664)	(0.0903)	(0.0702)
Government implicit price index	0.00380		0.00588
	(0.00326)		(0.00439)
PMPI		0.0348***	
		(0.00388)	
Log Age0_4	0.248***	0.659***	0.0577
	(0.0843)	(0.131)	(0.0802)
Log Age5_19	-0.563***	0.822***	-0.476***
	(0.130)	(0.268)	(0.128)
Log Age45_64	-0.326**	0.532*	-0.119
	(0.146)	(0.305)	(0.143)
Log Age75plus	-0.297***	0.523***	-0.360***
	(0.0897)	(0.125)	(0.0909)
Log Population	1.367***	-1.828***	1.343***
	(0.396)	(0.690)	(0.395)
P.E.I	-0.110	-0.636***	-0.0802
	(0.0876)	(0.116)	(0.0983)
Nova Scotia	0.0380	0.142**	0.0794
	(0.0499)	(0.0610)	(0.0516)
Newbrunswick	0.0828***	0.0566	0.107***
	(0.0302)	(0.0411)	(0.0305)
Quebec	0.251	0.831***	0.293
	(0.162)	(0.205)	(0.179)
Ontario	0.396**	0.958***	0.459**
	(0.199)	(0.236)	(0.222)
Manitoba	0.173**	-0.165**	0.288***
	(0.0676)	(0.0763)	(0.0732)
Saskatchewan	0.177***	-0.235***	0.286***
	(0.0636)	(0.0793)	(0.0663)
Alberta	0.0969	0.339**	0.201
	(0.141)	(0.136)	(0.163)
British Columbia	0.251*	0.332**	0.354**
	(0.138)	(0.160)	(0.158)
Year_1982	0.0960***		0.0801***
	(0.0293)		(0.0276)
Year_1983	0.129***		0.108***
	(0.0333)		(0.0326)
Year_1984	0.145***		0.129***

Covariates	Total	Pres. drug	Non-drug
	(0.0371)		(0.0382)
Year_1985	0.180***		0.158***
	(0.0446)		(0.0450)
Year_1986	0.221***		0.198***
	(0.0514)		(0.0511)
Year_1987	0.260***		0.231***
	(0.0567)		(0.0571)
Year_1988	0.298***	-0.0446*	0.256***
	(0.0645)	(0.0244)	(0.0654)
Year_1989	0.360***	0.00165	0.303***
	(0.0737)	(0.0239)	(0.0752)
Year_1990	0.420***	0.00683	0.345***
	(0.0828)	(0.0253)	(0.0859)
Year_1991	0.470***	-0.0440**	0.382***
	(0.0891)	(0.0222)	(0.0941)
Year_1992	0.505***	-0.0595***	0.404***
	(0.0928)	(0.0196)	(0.0988)
Year_1993	0.512***		0.400***
	(0.0967)		(0.103)
Year_1994	0.523***	0.0611***	0.397***
	(0.100)	(0.0185)	(0.108)
Year_1995	0.546***	0.221***	0.399***
	(0.106)	(0.0331)	(0.113)
Year_1996	0.557***	0.339***	0.395***
	(0.109)	(0.0464)	(0.116)
Year_1997	0.607***	0.420***	0.430***
	(0.113)	(0.0551)	(0.119)
Year_1998	0.672***	0.510***	0.476***
	(0.118)	(0.0644)	(0.124)
Year_1999	0.744***	0.583***	0.532***
	(0.123)	(0.0729)	(0.129)
Year_2000	0.809***	0.688***	0.570***
	(0.132)	(0.0859)	(0.138)
Year_2001	0.904***	0.807***	0.645***
	(0.138)	(0.0944)	(0.145)
Year_2002	0.957***	0.903***	0.676***
	(0.146)	(0.106)	(0.153)
Year_2003	1.013***	0.999***	0.713***
	(0.152)	(0.115)	(0.159)
Year_2004	1.040***	1.049***	0.725***
	(0.157)	(0.118)	(0.165)
Year_2005	1.091***	1.103***	0.760***
	(0.164)	(0.127)	(0.173)
Year_2006	1.138***	1.182***	0.790***
	(0.172)	(0.138)	(0.179)
Year_2007	1.163***	1.232***	0.809***
	(0.182)	(0.148)	(0.192)
Year_2008	1.196***	1.269***	0.841***

Covariates	Total	Pres. drug	Non-drug
	(0.187)	(0.154)	(0.197)
pmpi		0.0348***	
		(0.00388)	
Constant	-4.352***	-3.053	-5.142***
	(1.117)	(2.072)	(1.126)
Observations	280	220	280
R-squared	0.999	0.999	0.999

Notes: PMPI: Patented Medicines Price Index; Omitted earliest year = 1981 for total health expenditure and for nondrug expenditure regressions, due to government expenditure measures being unavailable before 1980; Omitted year = 1987 for drug expenditure regression due to PMPI data starting only from 1987; Nondrug expenditure = total health expenditure - prescription drug expenditure; Estimated standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 3. Validation models of nominal health expenditure

Covariates	Total	Pres. drug	Non-drug
CT	0.000230	-0.000158	0.000240
	(0.000990)	(0.00152)	(0.00108)
MRI	0.000205	-0.000220	-0.000192
	(0.000913)	(0.00138)	(0.000948)
Log family physician	0.123**	0.197**	0.0937
	(0.0565)	(0.0880)	(0.0577)
Log specialist	0.207**	0.0221	0.215**
	(0.0842)	(0.123)	(0.0869)
Log personal_expend	0.663***	-0.275	0.759***
	(0.197)	(0.293)	(0.213)
Log govern expend	0.133	0.0661	0.145
	(0.0998)	(0.101)	(0.108)
Government implicit price index	-0.000646		-0.000520
	(0.00404)		(0.00427)
PMPI		-0.143***	
		(0.0380)	
Log Age0_4	0.473***	0.444**	0.507***
	(0.158)	(0.221)	(0.165)
Log Age5_19	1.489***	0.691	1.619***
	(0.414)	(0.558)	(0.443)
Log Age45_64	1.715***	0.224	1.926***
	(0.373)	(0.695)	(0.400)
Log Age75plus	0.0311	0.676**	-0.00873
	(0.174)	(0.302)	(0.185)
Log Population	-3.832***	-1.486	-4.142***
	(0.915)	(1.359)	(0.986)

Covariates	Total	Pres. drug	Non-drug
P.E.I	-0.00105	-0.795***	0.155
	(0.161)	(0.212)	(0.169)
Nova Scotia	-0.0930	0.174**	-0.158
	(0.113)	(0.0862)	(0.120)
Newbrunswick	0.0869	0.120	0.0544
	(0.0776)	(0.0791)	(0.0807)
Quebec	-0.144	1.224***	-0.447
	(0.345)	(0.335)	(0.364)
Ontario	-0.0430	1.475***	-0.385
	(0.420)	(0.366)	(0.443)
Manitoba	-0.0128	-0.0419	-0.0657
	(0.154)	(0.126)	(0.162)
Saskatchewan	-0.0168	-0.126	-0.0604
	(0.157)	(0.177)	(0.165)
Alberta	-0.0961	0.685***	-0.276
	(0.260)	(0.190)	(0.273)
British Columbia	-0.0518	0.624***	-0.240
	(0.288)	(0.219)	(0.304)
Year_1992	-0.00674	0.436***	-0.0173
	(0.0135)	(0.116)	(0.0149)
Year_1993	-0.0456**	0.519***	-0.0677***
	(0.0228)	(0.135)	(0.0247)
Year_1994	-0.0799**	0.445***	-0.112***
	(0.0356)	(0.122)	(0.0388)
Year_1995	-0.107**	0.222***	-0.154***
	(0.0466)	(0.0587)	(0.0510)
Year_1997	-0.144*		-0.210**
	(0.0758)		(0.0833)
Year_2001	-0.0921	0.508***	-0.202
	(0.141)	(0.107)	(0.155)
Year_2003	-0.0767	0.720***	-0.211
	(0.167)	(0.150)	(0.184)
Year_2004	-0.0831	0.915***	-0.228
	(0.179)	(0.193)	(0.196)
Year_2005	-0.0684	1.079***	-0.221
	(0.193)	(0.233)	(0.211)
Year_2006	-0.0545	1.132***	-0.216
	(0.205)	(0.240)	(0.225)
Year_2007	-0.0651	1.174***	-0.234
	(0.219)	(0.254)	(0.239)
Constant	6.371**	18.83***	5.645**
	(2.455)	(3.581)	(2.533)
Observations	120	120	120
R-squared	1.000	0.999	1.000

Notes: PMPI: Patented Medicines Price Index; Omitted earliest year = 1991, as CT and MRI measures are not available before 1991; Nondrug expenditure = total health expenditure - prescription drug expenditure; Data on other medical technology such as PET, angiography etc are available only for 5 years, so they are

not included to avoid losing observations. Estimated standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix 2 Likelihood tests of model specification choice

Model specification	Restricted log likelihood		
	Total health expenditure	Drug expenditure	Nondrug expenditure
Linear (y)	-2654.6903	-1693.8712	-2654.3719
Log form (log y)	-1722.252	-964.76172	-1689.6209
Inverse (1/y)	-2574.886	-1617.2138	-2524.501

Note: Model specification with largest likelihood value is preferred. Technically, twice the difference in the log likelihoods of competing models is distributed as chi squared with one degree of freedom. The standard critical value for such a test is 3.84. Such tests support the log models.

Appendix 3 Data sources and description

A1. Provincial level data

Data description	Data Source	Details
Income		
GDP	Statistics Canada CANSIM	Table 384-0013
Net provincial government expenditure on goods and services	Statistics Canada CANSIM	Table 380-0017
Personal expenditure on goods and services	Statistics Canada CANSIM	Table 380-0017
Price index		
Government expenditure implicit price index	Statistics Canada CANSIM	Table 380-0056
Demographics		
Population by age and sex, province and year	Statistics Canada CANSIM	Table 051-0001
Health system capacity		
# of physicians by province and year	Scott's Medical Database	
# of specialists by province and year	Scott's Medical Database	
Number of diagnostic radiologists and nuclear medicine physicians	Scott's Medical Database and/or National Survey of Selected Medical Imaging Equipment	
Health expenditure		
Prescription drug expenditure, by province and year, 1985-2008	CIHI, Drug Expenditure in Canada, 1985 to 2010	Table B.
Nondrug expenditure	Calculated by authors	Hospital + physicians + other professionals + other institutions capital + administration + public health + over-the-counter drugs
Hospital	CIHI Expenditure data	Table D.

Data description	Data Source	Details
	2010, Series D1	
Other institutions	CIHI Expenditure data 2010, Series D1	Table D.
Physicians	CIHI Expenditure data 2010, Series D1	Table D.
Other professionals	CIHI Expenditure data 2010, Series D1	Table D.
Medical technology		
Number of MRI and CT Scanners by province and year, 1991-2008	National Survey of Selected Medical Imaging Equipment , CIHI	
Number of angiography suites, catheterization labs, PET scanners, and PET/CT Scanners by province, 2003-2008	National Survey of Selected Medical Imaging Equipment, CIHI	
Medical technology use		
The number of exams performed by MRI, CT Scan, PET/CT and SPECT/CT, 2003 to 2010	National Survey of Selected Medical Imaging Equipment , CIHI	

A2. National level data

Data description	Data Source	Details
New drugs approved		
# of new drugs approved (first in class, follow-on, and generic)	Health Canada Drug Product Database	Retrieved May 4, 2011
Demographics		
Population by age and sex, province and year	Statistics Canada CANSIM	Table 051-0001
Income		
Sum of net provincial government expenditure on goods and services for all provinces	Calculated by authors from provincial data	
Price index		
Government expenditures implicit price index	Statistics Canada CANSIM	Table 380-0056
Patented Medicine Price Index (PMPI), 1987-2008	PMPRB	2010 Annual Report
Health expenditure		
Prescription drug expenditure, by year, 1985-2008	CIHI, Drug Expenditure in Canada, 1985 to 2010	Table A.