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Health Human Resources Planning in a Health Care Production Context

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Introduction:

Health human resource planning has traditionally been based on the extrapolation of provider-population ratios to expected future populations (Birch 2002) with analyses being focused on the impact of demographic change on individual health care professions, e.g., the effect of an aging population on the requirements for particular health care providers, and the effect of an aging workforce on the capacity to meet requirements (Denton et al. 1993, 1995, Newton and Buske 1998, Kazanjian 2000, Kazanjian et al. 2000, Shipman et al. 2004). As a result the process has been restricted to analyzing the impact of demographic change on the capacity of the health workforce relative to the size of the population being served and involves implicit assumptions of constant levels of both health care productivity and age specific health care needs in the population. Birch et al. (2003) argued that health care services are produced by the combination of various human and non-human resources (or factor inputs), and the quantity (and quality) of health care services will depend on the level and mix of inputs used and the methods of production (or technologies) employed. In this way health care services are the outputs of a health care production process. Two important implications emerge from analyzing health human resources as part of the health care service production process:

1. The rate of productivity of a particular input (i.e., the ratio of quantity of outputs produced to the level of input used) will depend on the levels of other types of inputs, e.g., the number of episodes of inpatient care a given nurse workload can support will be affected by, *inter alia*, the number of hospital beds, operating room time, allied health staff, management support, type and severity of patient needs etc. For example, changes in the use of dental auxiliaries in the UK were found to be associated with substantial increases in dentist productivity (Gray 1982).

2. The required number (and type) of health human resources is derived from the required level of services and the availability of other human and non human resources. For example Richardson et al. (1998) considered the implications of employing non-physician personnel for the required number of physicians.

Often in policy discussions about health human resources, productivity is misinterpreted to mean the quantity of inputs provided by a particular group of health care workers. For example the increasing share of females in the physician workforce has been associated with a reduction in the average number of hours of work per annum by physicians that are then interpreted as a reduction in average physician productivity. Calls for increasing productivity are then viewed as attempts to increase the length of the average working week of physicians. However this approach fails to distinguish between three separate determinants of health care supply, the rate of participation (the proportion of individuals who are qualified to deliver care that are engaged in the delivery of care), the rate of activity (the amount of time devoted to the delivery of care by those engaged in the delivery of care) and the rate of productivity (the quantity of care provided *per unit time* engaged in care delivery).

Birch et al. (2003) illustrated the complex nature of health care production by analyzing the employment of nurses in acute care hospitals in Ontario. The analysis found that hospital-based nurse productivity, measured by the average number of inpatient episodes of care per full time equivalent nurse, was associated with both the bed capacity of the hospital and the average severity level of the inpatients. Over a 5 year period during which hospital bed capacity was reduced by 20%, average inpatient episodes per nurse fell by 2 per cent. However after allowing for changes in the average severity level of inpatients over the 5 year period, severity standardized episodes per nurse increased by more than 9%.

Increasing productivity has been identified as a particularly productive approach to increasing health care system capacity and efficiency (Birch et al. 2007). Moreover, failure to identify changes in productivity undermines HHRP processes by overestimating HHR requirements and the costs of health care services. The risk of planning for too many providers as a result of failing to take account of changes in provider productivity was identified in an appraisal of UK government plans to increase admissions to dental schools (Birch and Maynard 1985). In Canada, Newton and Buske (1998) suggested the country faced a possible future shortage of physicians based on an estimated 31% reduction in the estimated physician-population ratio over the next 25 years. However, Birch et al. (2007) note that if the average productivity of physicians were to increase by 1 per cent per annum and average age and gender specific needs for care were to fall by 1 per cent per annum over this period, the physician-population ratio, after allowing for these changes, would *increase* over the same period by 27 per cent. Hence, existing plans for physician training would be associated with more than enough physicians to maintain levels of services per capita after allowing for aging of the population. Consequently, consideration might need to be given to reductions in, as opposed to (or in addition to) expansion of, training programmes.

Although health economics research has embodied analyses of production processes from the earliest days of the discipline, both in terms of the production of health care and the production of health in populations (Feldstein 1967, Fuchs 1974, Auster et al. 1969), little use has been made of employing production functions, that set out the mathematical relationships between the levels and mix of different inputs and the levels of service outputs, to derive health human resource requirements, or to develop plans for meeting those requirements. For example, over the last decade a substantial literature has emerged on the application of advanced estimation techniques (Data Envelopment Analysis (DEA) and Stochastic Frontier Modelling (SFM)) to the measurement of performance of health care systems (Newhouse 1994, Skinner 1994, Vitalano

and Toren 1994, Kooreman 1994, Gerdtham et al. 1999, Hollingsworth et al. 1999, Chilingerian and Sherman 2004, Jacobs, Smith and Street, 2006) or individual elements of those systems (Ozcan and Luke 1993, Hadley and Zuckerman 1994, Chilingerian 1995, Burgess and Wilson 1996, Tambour 1997, Hollingsworth et al. 1999, Bryce et al. 2000, Cooper et al. 2000). Unlike regression models which are designed to explain observed variations in the dependent variable (e.g., outputs) in terms of variations in independent variables (e.g., inputs), these advanced methods are concerned with identifying what is the maximum level of outputs for given levels and mixes of inputs (or what is the minimum level of outputs required to produce a given level of outputs). In this way the level of inefficiency can be measured for individual production units (e.g. hospitals). However to date these approaches have not been used to inform health human resources planning. Yet such approaches would seem to offer an opportunity to identify health human resource requirements within the context of the planned service levels and the availability of other health care inputs. In this paper we consider the implications of changes in health care production for health human resource requirements in the context of the provision of inpatient services in acute care hospitals in three Canadian provinces. The aim is to ultimately address the following four research questions:

1. What has happened to the rate of output of nurses in recent years?
2. Do the observed changes differ across provinces?
3. What factors influence changes in the rate of outputs over the period?
4. What is the appropriate level of nursing inputs for particular levels of service delivery given different levels and combinations of other inputs?

However the current research represents work in progress that explores differences between the provinces as well as changes over time within the constraints imposed by available data.

Methods:

For the first two research questions we follow the approach of Birch et al. (2003) by calculating the average number of inpatient episodes of care per full time equivalent (FTE) inpatient nurse by province. The province is used as the unit of analysis because health care is a provincial responsibility within Canada and hence policies concerning the funding and delivery of health care vary between provinces. However, the pattern of 'episodes per nurse' over time may be explained by changes in the type and mix of patients being admitted to hospital. In order to consider whether the observed patterns are the result of changes in average needs of patients over time the number of episodes of care in a province is 'weighted' by the severity level of patient as indicated by the resource intensity weight of each inpatient episode. Resource intensity weights are derived by Provincial Ministries from data on the average cost of patients by condition and severity classification. This provides a measure of severity-adjusted inpatient episodes of care and implies that any changes in nurse productivity observed using the severity-adjusted measure cannot be explained by changes in the characteristics of patients admitted to hospital.

For the third research question we 'explain' variations in average nurse productivity (after severity adjustment) between hospitals in terms of the levels of other hospital inputs using regression models. The other inputs considered as possible determinants of nurse productivity include the number of FTE administrative staff, the number of FTE diagnostic and therapeutic staff (these are the allied health professionals and do not include physicians who work as fee for service independent contractors to ministries of health) and the number of funded hospital beds (i.e., does not include beds that are unavailable for use as a result of the budgetary plans of the hospital set by ministries). In particular each of these inputs may support or constrain nurses in the production of inpatient

care. Low levels of administrative staff may be associated with higher administrative burdens being passed on the nursing staff and hence reducing productivity. Alternatively a greater level of other allied health professions may lead to reductions in the time taken for diagnosis, treatment and rehabilitation and hence complement nursing inputs in the production of patient health improvements. The number of beds could have positive or negative impact on nurse productivity. A relatively low number of beds inhibit the flow of patient admissions to hospital leading to nurses devoting an excessive amount of time and effort to those who are admitted. Alternatively a relatively high number of beds could be associated with inappropriately high average lengths of stay as nurses do not have enough time to devote the appropriate intensity of care to each patient, thus slowing down the recovery process of the patient.

Finally, for the fourth research question we use DEA to initially estimate the efficiency of hospitals across provinces. DEA is a linear programming based method commonly used in assessing the efficiency of decision making units (DMUs) (see Hollingsworth, 2003). It allows a comparison to be made of hospitals relative to a best practice frontier, made up of those hospitals performing efficiently relative to others in the sample. It is based on the economic theory of production, ie the technical efficiency of the relative use of inputs to produce outputs, initially formulated into radial measures by Farrell (1957). In the model used here efficiency is estimated based on a model of one output (severity adjusted episodes of care), and 10 inputs: administrative hours; diagnostic hours; hotel hours; bed capacity; and six categories of nursing hours (administrative; intensive care; medical/surgical; obstetrics; paediatrics; and psychiatric). A variable returns to scale DEA model is used (as the hospital sizes vary dramatically) and an input oriented model (assuming hospital outputs to be largely exogenously determined through the budgetary setting processes of the Ministries of Health. The data are pooled across all three provinces and years to obtain a meaningful sample size.

Data:

The Discharge Abstract Database (DAD) was used as the source of data on inpatient episodes of care. This database is managed by the Canadian Institute of Health Information based on data provided by each province on hospital inpatient services. It provides a standardized record of each inpatient case at discharge including age and gender of patient as well as diagnoses, procedures received and length of stay. A separate database, Management Information System (MIS), records information on hospital resources including nursing, administration, 'hotel' and diagnostic and therapeutic hours. Each province records information on this system. However the quality and comprehensiveness of the data differs by province at this stage due to the recent phased implementation of the system.

Because data on the hours of nursing were not available separately for registered nurses and registered practice nurses for all three provinces for all years the two categories of nursing were combined. Data on worked nursing hours was used since benefit hours (sick time and vacation) do not represent time that nurses are available for service delivery. Inpatient nursing hours were given by the aggregate of hours across medical/surgical, obstetrics, pediatrics, psychiatric and rehabilitation. Nursing administration hours were identified specifically for inpatient care. Total worked hours per year by were divided by 1950 to provide an estimate of full time equivalent (FTE) nursing hours by the five categories of nursing for each acute care hospital in each of the three provinces. As a measure of capacity constraints the number of beds (rated bed capacity) of each hospital was used.

The number of inpatient episodes was 'weighted' by the Resource Intensity Weight (RIW) score for inpatient cases. Average RIW scores were calculated for

each of five age groups (0-4, 5-19, 20-64, 65-74, 75+) and then multiplied by the total number of inpatient stays by patients in each of these age groups. In this way allowance was made to changes in the age and severity mix of inpatients over time. The final data set covered 152 acute care hospital years from three provinces across 4 years (1998-2001). However 126 of the hospitals were from one province (Ontario) while data for the 2 hospitals in Prince Edward Island were only available for the period 1999-2001. Although the intention was to include other provinces in the study these provinces were unable to provide data on the hours of staff time by category of staff.

Results:

Table 1 reports on the levels of and changes in inpatient episodes and service inputs over the four year period 1998-2001. Inpatient episodes per FTE nurse fell in all three provinces over this period. Following adjustment for patient severity the rate of reduction in average nurse productivity was lessened and in the case of New Brunswick, severity adjusted productivity increased by over 1.25 per cent per year. It is worth noting that this was a period of economic growth and loosening of the fiscal constraints of the mid 1990s. In the case of Ontario, widespread hospital bed closures of around 20 per cent had led to increasing pressures on nurses to deal with a smaller but more resource intensive inpatient population while reducing average length of stay. The increased nursing inputs in Ontario may therefore reflect the relaxation of some of this pressure as increased funding was devoted to nursing in response to problems of nurse recruitment and retention and reports of nurse 'burnout'. Despite a modest increase in the number of beds, productivity per bed increased after allowing for severity adjustment. In other words, although there is no evidence that nursing productivity increased over this time, the increased levels of nursing input were employed in ways that supported both an increased number of beds and an increase in the throughput of beds, in terms of severity-adjusted caseloads. In the case of New Brunswick, both adjusted episodes per nurse and adjusted

episodes per bed increased. The PEI data are based on only 2 acute care hospitals and indicate that although outputs and inputs were reduced over the period, the rate of reduction in adjusted episodes exceeded the rates of reduction in nursing hours and beds implying a reduction in average productivity.

Table 1
Hospital-Based Services in Ontario, New Brunswick and Prince Edward Island 1998 to 2001[1]

	Ontario			New Brunswick			Prince Edward Island		
	1998	2001	% change	1998	2001	% change	1999	2001	% change
Population (000's)	11,348	11,866	4.56	751	750	-0.13	136	137	0.74
Inpatient Episodes (000's)	1,093	1,086	-0.64	102	96	-5.88	14	13	-7.14
Number of FTE Nurses[2]	24,727	27,042	9.36	2,906	2,819	-2.99	399	392	-1.75
Beds	25,394	25,912	2.04	3,460	3,460	0.00	387	386	-0.26
Inpatient Episodes per 100 Population	9.63	9.15	-4.98	13.58	12.80	-5.74	10.29	9.49	-7.77
Inpatient Episodes per FTE Nurse	44.22	40.15	-9.20	35.14	34.02	-3.19	35.90	33.76	-5.96
Inpatient Episode per Bed	43.06	41.90	-2.69	29.51	27.71	-6.10	37.02	34.25	-7.48
Adjusted Inpatient Episode per FTE Nurse	56.84	56.34	-0.88	41.81	44.06	5.38	42.94	41.22	-4.01
Adjusted Inpatient Episode per Bed	55.35	58.80	6.23	35.11	35.89	2.22	44.29	41.82	-5.58

[1] Data from 126 acute care facilities in Ontario, 24 in New Brunswick and 2 in Prince Edward Island. The 1998 data for Prince Edward Island are unavailable.
[2] Includes only those nursing hours from medical/surgical, obstetrics, pediatrics and psychiatry departments within acute care facilities. An FTE nurse is assumed to have worked 1950 hours per year.

Table 2 presents the estimated coefficients on non nursing inputs in the regression equation explaining variation in average severity-adjusted inpatient episodes per FTE nurse. Two different models are presented with model 2 including a 'beds squared' term to allow for non linearity in the relationship between average nurse productivity and beds.

Both beds and diagnostic/therapeutic staff are significantly associated with differences in average productivity. However while a greater numbers of beds is associated with higher average productivity, higher levels of allied health professional staff are associated with lower average nurse productivity. One possible explanation of this is that higher levels of allied health staff may lead to more investigations and procedures, hence imposing more demands on nurses and extending inpatient lengths of stay. This may be associated with better patient outcomes but in the absence of any direct measure of patient health status investigating this further is beyond the capacity of this study. Productivity is less in both New Brunswick and PEI, which may reflect the much larger average size of hospitals in Ontario, the most populous province in the country compared to New Brunswick and PEI, two of the smallest provinces. This is supported by the introduction of the 'beds squared' term which suggests productivity increases at an increasing rate with the number of beds, at least within the range of hospital sizes considered in this study. There is no evidence of changes in average productivity over the period of study.

Table 2
Ordinary Least Squares Regression
Ontario, Prince Edward Island, New Brunswick 1998-2001[2]
(p-values in parentheses)

	Dependent Variable: RIW Adjusted Discharges per FTE Non-Administrative Nurse[1]	
Variable	**Coefficient** (p-value)	
	Model 1	**Model 2**
Administrative and Housekeeping Hours	5.955e-7 (0.5304)	7.599e-7 (0.4194)
Diagnostic and Therapeutic Hours	-4.770e-5 (0.0001)	-5.156e-5 (0.0001)
Beds	0.0214 (0.0076)	-6.071e-4 (0.9516)
Beds Squared	--	2.904e-5 (0.0003)
Dummy=1 if 1999	0.3377 (0.8528)	0.2751 (0.8787)
Dummy=1 if 2000	0.5486 (0.7634)	0.5658 (0.7539)
Dummy=1 if 2001	2.138 (0.2458)	2.147 (0.2392)
Dummy=1 if PEI	-29.800 (0.0001)	-28.421 (0.0001)
Dummy=1 if NB	-24.958 (0.0001)	-25.112 (0.0001)
Intercept	76.370 (0.0001)	78.515 (0.0001)
Adjusted R Squared	0.404	0.415
observations	605	605

[1] Includes only those nursing hours from medical/surgical, obstetrics, pediatrics and psychology departments within acute care facilities. An FTE nurse is assumed to have worked 1950 hours per year.
[2] Includes 126 acute care facilities in Ontario (1 hospital excludes 1999 data), 24 in New Brunswick and 2 in Prince Edward Island. The 1998 data for Prince Edward Island are unavailable.

The initial results for the estimates of efficiency are presented in Table 3. Ontario hospitals 'drive' the efficiency frontier, which was expected given the unbalanced data set. Efficiency changes across time are not dramatic which provides support for the finding in the productivity estimates of no significant changes over time. Moreover, although efficiency in the provision of inpatient care in Ontario hospitals appears to be steady, there is some indication that inpatient efficiency in New Brunswick and PEI has slipped relative to the overall sample.

Table 3: Mean efficiency scores by province and year

	ONT	*NB*	*PEI*	*ALL*
1998	0.858	0.677	-	0.830
1999	0.860	0.658	0.689	0.826
2000	0.859	0.632	0.648	0.821
2001	0.865	0.600	0.653	0.822

The next stage in the analyses is to break down the individual hospital results to see what is driving the inefficiency in terms of the relationship between the weights on the inputs. This will help us see if it is, for example, bed capacity, or certain categories of nurse use which are driving inefficiency and allow us to determine the efficient number of FTE nurses for a given level of output and other input levels.

Discussion:

The purpose of this research was to explore the question of health human resource productivity in order to inform health human resource planning policy. Both clinical and management policies can lead to changes in health human resource productivity. Moreover, the underlying rationale for many such policy developments would appear to be related at least in part to the desire for productivity improvements (e.g., introduction of laparoscopic surgery, increased use of day-case patients etc). Yet the notion of productivity change has not generally been introduced into health human resource planning. The analysis

presented in this paper, although representing only a preliminary attempt to consider the question of productivity change, does indicate that in the case of inpatient nursing care over a 3-4 year period, the rate of service output, as measured by severity-adjusted inpatient episodes of care, has changed and that the direction and rate of change has differed between provinces. Moreover the findings indicate that the levels of employment of other hospital-based staff are significantly associated with the average productivity of nurses. As such, the required number of nurses to deliver a planned level of service (or manage a particular patient mix) will depend on the configuration of other hospital inputs (i.e., it is context specific). The efficient number of nursing service inputs will depend on the identification of the efficiency frontier using techniques such as DEA.

It is important to recognize that the analysis is constrained by the nature and quality of data and the contribution of this type of research to policy developments will depend on appropriate data being collected and made available to researchers. In this research we found that data on hours of staff time by different category of staff were only available for a small number of provinces. Moreover, even where these data were available, there were many challenges presented to using the data. Data were not generally available for different staff levels within a particular category, allocations of staff time between categories (e.g., hospital administration and nurse administration) appeared to shift over time while levels of staff time are generally limited to directly employed staff and hence sensitive to the use of contracting out of some services (e.g., hotel services).

Similarly, the study was limited to focusing on inpatient episodes of care in acute care hospitals. Although significant levels of hospital care are now provided in non-inpatient settings, and some hospital functions will cover both inpatient and outpatient settings, data on non-inpatient care (outpatients and emergency department) are largely limited to basic patient counts with little or no

information on case severity. Clearly these activities represent important areas for planning both human and non-human health care resources in their own right. But these activities may also affect staff productivity in inpatient care.

Finally, our concept of productivity is based on the production of inpatient episodes of care after allowing for differences in patient severity. However this does not take account of health outcomes of inpatient care. Of course outcomes may depend on more than just the service provided as an inpatient. The services available, both formal and informal, to support the patient post discharge as well as the particular characteristics of the patient and his or her social and economic environments may affect the impact of inpatient care on health. Hence determining the contribution of the inpatient care to the overall health of the patient becomes a complex matter. Nevertheless in other work consideration was given to the relationship between inpatient nursing care, average inpatient length of stay and several indicators of health outcomes (hospital readmission within 30 days of discharge, patient satisfaction with care and self assessed health status) for acute care hospitals in Ontario (Tomblin-Murphy et al 200X). Hospitals with significantly higher levels of nursing inputs were found to have significantly lower average lengths of stay but no evidence was found that this was reflected in lower levels of patient outcomes.

References:

Andes S, Metzger L, Kralewski J, Gans D. (2002) Measuring Efficiency of Physician Practices Using Data Envelopment Analysis, Managed Care, 48-55

Auster R, Leveson I, Sarachek, D. (1969) The production of health: An exploratory study, Journal of Human Resources, 4, 412-436.

Birch S. (2002) Health human resource planning for the new milenium: Inputs in the production of health, illness and recovery in populations. Canadian Journal of Nursing Research, 33: 109-114.

Birch S, Maynard A. (1985) Dental manpower. Social Policy and Administration, 19:199-217.

Birch S, O'Brien-Pallas L, Alksnis C, Tomblin-Murphy G, Thomson D. (2003) Beyond demographic change in human resources planning: an extended framework and application to nursing. Journal of Health Services Research and Policy, 8: 225-229.

Birch S, Kephart G, Tomblin-Murphy G, O'Brien-Pallas L, Alder R, MacKenzie A. Human resources planning and the production of health: A needs-based analytical framework. Canadian Public Policy 33; S1-S16.

Bryce C, Engberg J, Wholey D. (2000) Comparing the agreement among alternative models in evaluating HMO efficiency. Health Services Research 35: 509-52.

Burgess, J, Wilson P. (1996) Hospital Ownership and Technical Efficiency, Management Science 42: 110-123

Chilingerian J. (1995) Evaluating Physician Efficiency in Hospitals: A Multivariate Analysis of Best Practices. European Journal of Operational Research, 80, 548-574

Chilingerian, J, Sherman H. (1997) DEA and Primary Care Physician Report Cards: Deriving Preferred Practice Cones for Managed Care Service Concepts and Operating Strategies, Annals of Operations Research, 73, 35-66

Cooper W, Park K, Pastor J. (2000) Marginal Rates and Elasticities of Substitution with Additive Models in DEA, Journal of Productivity Analysis, 13, 105-123

Denton F, Gafni A, Spencer B. (1993) The SHARP computer system - A tool for resource planning in the health care sector, in Strategic Issues in Health Care Management, M.Malek, J. Rasquinha and P. Vacani, Eds. London: John Wiley and Sons.

Denton F, Gafni A, Spencer B. (1994) System for Health Area Resource Planning (SHARP): an application to Ontario medical school enrolment. Canadian Medical Association Journal, 1151: 39-45.

Denton F, Gafni A, Spencer B. (1995) The SHARP way to plan health care services: A description of the system and some illustrative applications in nursing human resource planning. Socio-Economic Planning Sciences, 29: 125-137.

Denton F, Spencer B. (2000) Population aging and its economic costs: A survey of the issues and evidence. Canadian Journal on Aging, 19 (supplement 1): 1-31.

Dor A. (1994) Non-minimum cost functions and the stochastic frontier: On applications to health care providers. Journal of Health Economics, 13, 329-334.

Eastaught S. (2002) Hospital Nurse Productivity, Journal of Health Care Finance, 29, 14-22

Farrell M. (1957) The measurement of productive efficiency. *Journal of the Royal Statistical Society* Series A; (III): 253-290.

Feldstein M (1967) Economic analysis for health service efficiency: Econometric studies of the British National Health Service. Amsterdam: North Holland.

Fuchs V. (1974) Who shall live? Health, economics and social choice. New York, Basic Books.

Gerdtham U, Lothgren M, Tambour M, Rehnberg C. (1999) Internal Markets and Health Care Efficiency: A Multiple-Output Multiple-Input Stochastic Frontier Analysis, Health Economics 8, 151-164

Gray A. (1982) The production of dental care in the British National Health Service. Scottish Journal of Political Economy, 29: 59-74.

Hadley J, Zuckerman S. (1994) The role of efficiency measurement in hospital rate setting, Journal of Health Economics, 13, 335-340.

Hollingsworth, B. (2003). Non-parametric and parametric applications measuring efficiency in health care. *Health Care Management Science*; 6(4): 203-218.

Hollingsworth B, Parkin D. (2001) The Efficiency of the Delivery of Neonatal Care in the UK, Journal of Public Health Medicine, 23, 47-50

Hollingsworth B, Dawson P, Maniadakis M. (1999) Efficiency Measurement of Health Care: A review of Non-Parametric Methods and Applications, Health Care Management Science, 2, 161-172

Jacobs R, Smith P, Street A. (2006) Measuring efficiency in health care: Analytic techniques and health policy. Cambridge: Cambridge University Press.

Kazanjian A. (2000) Nursing Workforce study: Volume 5. Changes in the nursing workforce and policy implications. Vancouver: University of British Columbia.

Kazanjian A, Rahim-Jamal S, Wood L, MacDonald A. (2000) Nursing workforce study: Volume 1. Demographic context in health system structure for nursing services in Canada. Vancouver: University of British Columbia.

Kooreman P. (1994) Nursing home care in the Netherlands: a non-parametric efficiency analysis, Journal of Health Economics, 13, 301-316

Newhouse J. (1994) Frontier Estimation: How Useful a Tool for Health Economics?, Journal of Health Economics, 13, 317-322

Newton S, Buske L. (1998) Physician resource evaluation template: A model for estimating future supply in Canada. Annals of the Royal College of Physicians and Surgeons of Canada, 31: 145-150.

Nyman J, Bricker D, Link D. (1990) Technical efficiency in nursing homes, Medical Care, 28, 541-551

Ozcan, Y, Luke R. (1993) A national study of the efficiency of hospitals in urban markets, Health Services Research, 27, 719-739

Shipman S, Lurie J, Goodman D. (2004) The general pediatrician: Projecting future workforce supply and requirements. Pediatrics, 113: 435-442.

Skinner J. (1994) What do stochastic frontier cost functions tell us about efficiency? Journal of Health Economics, 13, 323-328.

Tambour M. (1997) The impact of health care policy initiatives on productivity, Health Economics, 6, 57-70.

Vitalano D, Toren M. (1994) Cost and efficiency in nursing homes: A stochastic frontier approach, Journal of Health Economics, 13, 281-300.