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MIND THE GAP?

Projecting demand
and supply for
healthcare professionals

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1 Introduction

Manpower or workforce planning, which is defined as "ensuring that the right people are available to deliver the right services to the right people at the right time" (1), is believed to be the appropriate approach to tackling the allocative and technical efficiency issues associated with the 'production' function of healthcare. Human resources for health (HRH) planning and forecasting is an important strategic objective in many countries and often reflects an increasing mismatch between the need/demand for and supply of healthcare professionals at regional as well as national levels.

Historically, HRH forecasting has been weakly linked to national health policies and population health needs. It was based on the assumption that more healthcare input produced better health, and was done by modelling supply, demand and need for manpower independently (2-4).

HRH forecasting is extremely complex and often framed by healthcare financing models and resources allocated to healthcare, service delivery models, the level and mix of healthcare services, controls on the volume and appropriateness of clinical activity, productivity, elasticity of supply, work-force complementarity and substitution (3, 5). Comprehensive forecasting models combine economic concepts with determinants of health, the peculiarities of the medical environment, and training time lags (6).

Modelling is an essential tool for manpower projections. Depending on the underlying assumptions, the models adopted may be deterministic or stochastic. Deterministic models are used when the outcome is certain, whereas stochastic models allow for uncertainty and flexibility in the model and deliver different results over multiple runs. Over time stochastic models are believed to reveal the most likely outcome, but they are more computational involved, use complex programming, and present analytical challenges. There are, however, also methodological limitations in these stochastic models including the lack of easily accessible clinical, administrative and provider databases for modelling, as well as conceptual challenges. Many of these models are of variable quality, and/or project only for (a) specific diseases(s) or professional group only. The quantity and quality of the data will directly determine how accurately the model reflects the real situation and therefore the reliability of the projections (7).

Considering the many factors that shape projection models (e.g. availability and quality of data, assumptions regarding characteristics of population change and growth, developments in medical technology, and/or clinical practice) selecting the model structure and attributes most suitable for the setting is essential. A number of projection models are described in the formal academic and grey literature; however, a comprehensive “gold standard” that fits all situations equally well remains elusive. There is little consensus on the best methods for estimating healthcare manpower in the literature. The most common approaches include workforce-population ratios, need-based, demand/utilisation-based, and supply models (8). Each method has its strengths and limitations and requires many compromises, simplifications, and assumptions.

2 Setting the scene

2.1 Models for policy level planning

2.1.1 Need-based models

Need-based models allow for estimates of true population need by considering changes in health status and efficacy of healthcare services (3, 8, 9) while adjusting for population size and characteristics including age, sex, household income, risk behaviour, and self-perceived health. These models project healthcare deficits as well as healthcare service need (both professional staff or quality of service to an optimum standard). As need-based approaches have greater data demands than approaches based on supply or utilisation, epidemiological data is an important limiting factor. For these models, detailed information on the efficacy of individual medical services for specific medical conditions is required (8). Although need-based models usually cannot account for historically unmet need they can avoid perpetuating existing inequity and inefficiency within the healthcare delivery system, a common problem with other forecasting models, however, the assumption that healthcare resources will be used in accordance with relative levels of need is seldom verified.

2.1.2 Demand/utilisation-based models

Demand/utilisation models are built on service utilisation data (8), under the assumption that healthcare workload remains constant over time, and population growth directly leads to increased workload (4, 9). Demand models commonly include 1) estimates of healthcare demand or at least historical utilisation patterns (most frequently by diagnosis), 2) anticipated change in practice patterns, 3) the impact of current and emerging technologies, and 4) policy change. The projections are often limited to age and sex although other characteristics of the population, market conditions, institutional arrangements, and patterns of morbidity may be included. Previous demand models have often assumed that doctors were required for all demanded service, current demand was appropriate, age and sex specific resource requirements were constant; and demographic change was predictable over time (8).

2.1.3 Benchmarking

Benchmarks refer to a current best estimate of a reasonable workforce. These estimates are valid for comparison only if communities and healthcare planning are comparable, i.e. adjusted for key demographic, health and health system parameters. Estimates of manpower requirements are based on healthcare worker-to-population ratios and current healthcare services. For such models to be relevant adjustments for differences in population demography, population health, health insurance, productivity and health system organization are important (8).

2.1.4 Trend analysis

Based on aggregate level, and time series historical data, trend analysis uses observed historical population growth and ageing trends for predicting future trends. It is a macro simulation based on the extrapolation of past trends. Trend analysis is often useful for projecting likely growth particularly in the private sector (7, 10). These models assume 1) a causal relationship between economic growth and the number of doctors per capita, 2) that future requirements will reflect current requirements (e.g. the current level, mix, and distribution of providers are sufficient), 3) productivity remains constant, and 4) demographic profiles (such as population growth) are consistent with observed trends (8, 11). Some argue these models have 'labour myopia' and should be revised to include determinants of doctor productivity and elasticity of labour supply for different provider groups (5). These models do not consider the evolution of the demand for care.

2.2 Learning from international organisations

2.2.1 World Health Organisation

The mission of the Department of Human Resources for Health, World Health Organisation (WHO), is to "provide equitable access for all people to an adequately trained, skilled, and supported health workforce to contribute towards the attainment of the highest possible level of health" (12). The strategic direction of the department is to provide technical and administrative coordination through several priority programmes one of which is the Health Workforce Information and Governance team. This team provides countries and other healthcare partners policy and planning advice, and technical support in the form of tools, guidelines, norms and standards on health workforce assessment, planning, monitoring and evaluation (7, 13-21). The WHO has identified three fundamental principles associated with the integration of healthcare service and the development of health personnel (13). First, the planning, production, and management functions for HRH must go together. Second, human resources are to serve the needs of the health system. Third, the health system must serve the people's needs. The WHO has developed a conceptual framework for HRH projection which pulls all these activities together. It consists of 4 different phases including: 1) situation analysis, 2) planning, 3) implementation, and 4) monitoring and evaluation (22). While the

HRH framework is applicable in all countries, its application will be influenced by elements specific to the country context. Figure 2.1 provides the outline adopted by the WHO to identify the mechanism by which balance in the requirements (demand for healthcare provision) and the supply can be achieved.

The WHO uses simulation as the tool to assess the potential impact of various strategies on change in the model outcomes. Both deterministic and stochastic processes can be applied to this model. Typically the variables included in these models are demographic growth and change; health policy and related legislation; technological change; burden of disease; service and provider utilisation; relevant service quality standards; organisational efficiency; skills mix; individual provider performance; public demand and expectations; and availability and means of financing. The most commonly used approaches to project workforce requirements are workforce-to-population; health-needs; service-demand; and service targets methods. Each has its advantages and disadvantages. Although supply side projections are relatively less complex and simpler, careful accounting is needed to ensure all relevant and available workers are included in the estimates. Aspects to consider are the capacity to produce healthcare workers, the different types of healthcare workers needed for future work, loss rates due to retirement, and emigration, death or pre-retirement leaving.

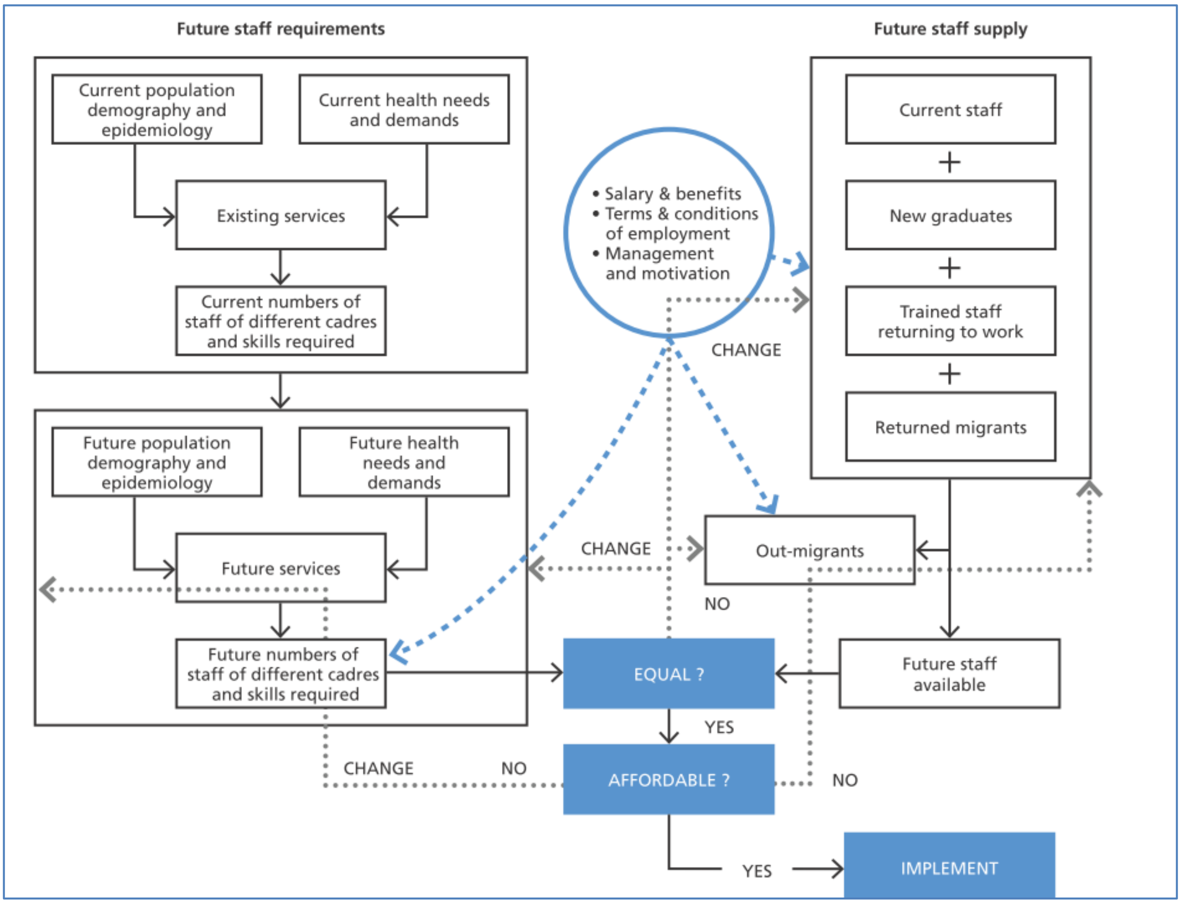

Figure 2.1 (reproduced from WHO original) WHO concepts for linking healthcare workforce requirements and supply projections (7)

2.2.2 Organisation for Economic Cooperation and Development (OECD)

The Health Division of the Directorate for Employment, Labor and Social Affairs of the OECD advises countries on how to meet future demand for health professionals and help countries improve health workforce planning (23). With a focus on doctors and nurses, the OECD has identified trends shaping the current and future health workforce in member states over the past decades in cross-country reports (24) and country-specific health system reviews (25). Both a prolonged increase in the supply of doctors and nurses across member states was identified. Factors identified as influencing the change in demand for doctors and nurses were increasing incomes, changing medical technology, and population ageing. Supply factors influencing the growth rate for doctors were controls on entry into medical school, for nurses capping the number of hospital beds, and for both professions: immigration, emigration, and changes in productivity (26). Factors likely to impact the shape and potential shortage of the future health workforce were: workforce ageing, feminisation, expectations of younger generations in terms of work-life balance, increasing specialisation, and changes in delivery of service such as an increase in day case treatment, and overall declining length of stay (26).

The OECD has also explored specific issues such as the impact of skill-mix and policy change on the health workforce (27), staff shortages (28), and strategies on how to adapt supply to a growing demand within particular workforce specialties (29).

The extensive work undertaken by the WHO and the OECD, and the development of manpower planning and forecasting tools by these organisations, are useful guides for manpower projections in Hong Kong. They provide an excellent source of benchmarking tools in the area of health manpower planning for both developing and developed countries.

2.3 Learning from overseas jurisdictions

To learn from international approaches to workforce planning, nine jurisdictions were selected for review – Australia (30), Canada (31), Japan (32), The Netherlands (33), New Zealand (34), Scotland (35), Singapore (36), United Kingdom (37), and the United States (38, 39) to determine: 1) strategies for national level manpower planning and forecasting; 2) methods used to project population level healthcare professional demand and supply, and 3) methods to improve workforce productivity and capability. **Appendix A (i), (ii) and (iii)** illustrates the context, framework, methods, and assumptions guiding these manpower planning and forecasting models. These jurisdictions were selected for the maturity of their manpower planning models, and comparability of workforce issues to Hong Kong.

2.3.1 Australia

Set up by the Council of Australian Governments and reporting to the Australian Health Ministers' Advisory Council, Health Workforce Australia (HWA) is responsible for projecting the healthcare manpower requirements in Australia, and advising and informing governing bodies on the dynamic changes in the healthcare workforce (30). HWA has adopted a 'models of care' approach based on competencies required for the delivery of the best healthcare. The HWA projects manpower requirements based on the expected change in model parameters (such as changes in immigration, innovation/technology, healthcare and health system reform, as well as skills or roles or healthcare professionals) through scenarios analyses.

The HWA 2025 healthcare workforce projection for midwives, registered and enrolled nurses used a stock and flow supply model and applied a constant linear growth rate model to calculate demand (40). Supply model parameters included graduates, immigration of nurses, no longer available for nursing practice, training time, and hours worked. The demand model parameters included total hospital bed-days by population growth, service related groups (similar to Diagnostic Related Groups), total number of aged care packages by population growth aged 70 years and over, service utilisation, total number of projected births, and total number of projected Registered Nurse (RN)/ Enrolled Nurse (EN) full time equivalent (FTE)[1] by population ratio (40).

The HWA adopted a similar model for the November 2012 projection of medical specialties. The stock and flow supply model parameters included workforce headcount, demographic characteristics, number of graduates and medical fellows, immigration of overseas specialists, lost to medical practice, FTE benchmarks, training time, and number of hours worked (40). The demand model parameters were service utilisation by sex and five-year age cohort, public/private hours worked, services related groups and enhanced service related groups. Diagnosis groups were used to assign medical services to medical specialties and sub-specialties (41) and to adjust for complexity of care (proxy for severity of illness). The assumption being that higher complexity inherently drives manpower requirements. These models derive estimates from a baseline year and assume a consistent linear future trend in healthcare need and technological change.

2.3.2 Canada

Prior to 2003, healthcare workforce planning in Canada was undertaken by each jurisdiction or province independently and did not address pan-Canadian supply and demand. In seven of the ten provinces, historical patterns of health service utilisation and health human resource supply, as proxies for public sector demand and supply, were used to project healthcare manpower requirements. The remaining three provinces adopted a need-based approach. Since 2003, Health Canada (a department of the federal government) has worked with the provinces and territories to improve coordination in and develop a conceptual model for human health resource planning (42). The proposal includes a stock and flow model for supply and a need-based model using utilisation of curative and preventive services (43).

[1] **Full-time equivalent** (**FTE**) is a standardized measure of time at work for an employed person. An FTE of 1.0 indicates a full-time worker, whereas FTE of 0.5 signals half-time.

More specifically, most jurisdictions calculated health workforce supply using parameters such as new local and non-local registrants, attrition, and employment status (44). Although many parameters were available to project manpower demand and supply, most of the provinces used historical trends (age and sex stratified) to project future healthcare workforce requirements (44). The newer projection models adopt additional supply-side parameters such as education, immigration, and career patterns (44). Overall, Canadian healthcare manpower demand models project FTE requirements on current utilisation patterns including parameters such as changes in the total population size and age-sex structure. Only two jurisdictions report including parameters such as socio-economic characteristics in the models or addressing the impact of externalities such as change in healthcare policy.

Although Health Canada is coordinating healthcare manpower planning and forecasting, as with most other health care issues, healthcare manpower regulation and registration, planning and forecasting remains the jurisdiction of the provinces. While there are similarities and commonalities between provinces, the models as developed and applied are broadly applicable only to the province of origin.

2.3.3 Japan

The Ministry of Health, Labour and Welfare (Japan) projects the supply and demand for healthcare personnel (45). The 7th Projection of Estimated Supply and Demand for Nursing Personnel was prepared in 2010, estimated a shortfall of 15,000 nurses in 2016 (46). The supply parameters included current employment status by year, local and international graduates, re-employment and retirement. The demand parameters included service utilisation by hospitals, clinics, maternity clinics, long-term care facilities, social welfare facilities, health centres and municipal facilities; educational institutions, workplaces, and schools (46). Currently, the full report of the 7th Projection of Estimated Supply and Demand for Nursing Personnel is not released, thus more specific methods are not publicly available. Historical trends were used to quantify but not project the demand for other healthcare professionals, such as doctors, dentists and pharmacists (46).

2.3.4 The Netherlands

The Netherlands Institute for Health Services Research (NIVEL) is an independent organisation with manpower planning as a particular area of research (47). NIVEL deployed stock and flow methods to project supply and demand for healthcare professionals (48).

Parameters used in their supply model included working capacity, primary activity, graduates, drop-out rates, expected age of retirement, working hours and task delegation (48). The supply model also incorporated the flow of medical professionals by sex in and out of the healthcare market and projected total FTE. The demand model (a three-part model) used simulation methods to project service utilisation on demographic and epidemiological developments (48). Part 1 established the baseline supply and demand of healthcare professionals by FTE adjusted by gender (49). The manpower gap between the supply and demand was then estimated. Part 2 projected supply and demand FTE requirements for the target year by projecting parameters such as demographic change, and the inflow and outflow of health professionals (49). Part 3 compared the expected manpower supply by FTE from labour market returns with projected FTE supply in three scenarios (49). The base scenario used trend analysis to forecast the impact of demographic change on the demand for healthcare. The first scenario included parameters such as epidemiological, socio-cultural and technical developments as well as, efficiency change, horizontal substitution and working hours per FTE in the demand model. The second scenario considered the impact of vertical substitution on demand (49).

Although a comprehensive methodology has been used for healthcare manpower planning in the Netherlands, the models generally draw on a subjective interpretation of the demand (expert opinion determines unmet demand).

2.3.5 New Zealand

In New Zealand, Health Workforce New Zealand (HWNZ) has the overall responsibility for planning and development of the health workforce, ensuring that staffing issues are aligned with planning on the delivery of services, and that New Zealand's healthcare workforce is fit for purpose (50). Currently, HWNZ is undergoing workforce service review with the objective of determining future health workforce requirements in 13 areas: aged care, anaesthesia, eye health, palliative care, musculoskeletal diseases, gastroenterology, youth health, diabetes, mental health, rehabilitation, mother and baby, healthcare for the Maori, and healthcare for Pacific Islanders (50). The HWNZ has used trend analysis and predicted service utilisation to determine future requirements.

The HWNZ has projected healthcare manpower (51) from the Health Workforce Information Programme. The supply model projection used a dynamic supply model to calculate headcount and FTE from historical trends of new graduates, return rates, and retirements rates. Model parameters included current workforce inflow and outflow, age, sex, ethnicity, and occupation (51). The demand model included the following parameters population growth, age, sex, ethnicity, change in service, change in the care model, and the impact of current and emerging technologies (51). HWNZ contends that due to the shift toward population based healthcare delivery, the total population health needs and achievements are of particular importance in the forecast for demand.

The projection models rely heavily on trend analysis and linear regression to estimate manpower requirements. While simple models can provide a quick snapshot of current needs of population they lack the dynamic variation in scenarios and may misrepresent the demand for healthcare.

2.3.6 Scotland

NHS Scotland Workforce section of Information Services Division has used trend analysis to assess the supply and demand of medical, dental, nursing and midwifery, allied health professions, health science, ambulance staff, psychology, and pharmacy workforce (52). Parameters such as changing demography, and service utilisation, were used for the demand models and, workforce dynamics, workforce inflows and outflows for the supply models (53).

Three methods, dynamic models (stock and flow), healthcare professional-to-population ratio, demand/utilisation-based models were used to project healthcare professional supply and demand. The model parameters included service utilisation, service delivery, changing models of care, workforce skill mix (roles and competencies), integration and engagement of the workforce across the professions, health and social care, and care by sector (primary, secondary and tertiary) attendance rate, treatment rates, and for dentists average quantity of treatment per dentist per year (54, 55).

The supply model adopts stock and flow methods, that are commonly used by many other countries. The demand/utilisation-based models, while more sophisticated, require extensive and complex data, are susceptible to larger measurement error than projections based on population ratios (53).

2.3.7 Singapore

The National Manpower Council of the Singapore Ministry of Manpower is the decision-making body for the National Manpower Planning Framework (56). The Council has adopted an approach, where the future demand for healthcare manpower is based on trend analysis of population demographics and current healthcare workforce supply (57). In 2009-2011, the overall supply of doctors, registered nurses, enrolled nurses, dentists, pharmacists and optometrists increased across the board (58). As at 2012, Singapore had 10,225 doctors, (doctor-to-population ratio of 1:520), 60% of whom work in the public sector (58); 34,507 nurses and midwives (nurse-to-population ratio of 1:150). Strategies to manage the in- and out-flows of healthcare professionals (i.e. doctor, specialist, nurse) and to recruit more internationally qualified healthcare professionals from developed countries have been put in place to reduce workload demand. Included in this approach is the talent outreach programme (36). The Healthcare 2020 Masterplan healthcare demand and workforce planning projection parameters (57) included population growth and ageing, education, healthcare sector productivity and change in healthcare worker role (i.e. role extension), immigration of foreign healthcare workers and changes in the service delivery model. The supply model includes education and training of local professionals, and the recruitment of non-local graduates.

The available data from the Ministry of Health are total number of healthcare professionals by sectors (i.e. private and public sectors), and the professional-to-population ratio or vice versa (58). No full-time equivalent information was considered are given. For some healthcare professionals, professional-to-doctors ratio was used in the trend analysis.

2.3.8 United Kingdom

The Centre for Workforce Intelligence (CWI) provides advice and information to health and social care systems on workforce planning and development in the United Kingdom (37). CWI works closely with various organisations such as the NHS Information Centre, the medical Royal Colleges, and other regulatory bodies to access the highest quality, accurate and timely data for healthcare manpower planning (37). The CWI has focused on the supply of various health professions, (medical, dental, nursing, midwifery, and other allied health professionals). CWI released several reports in 2012 on technological, economic, environmental, political, social, and ethical factors that they consider/use in their supply and demand projection models (59, 60). Parameters used in the stock and flow model for medical and dental supply include current workforce, workforce participation, working time spent delivering service, active workforce, number of entering and returning to workforce, immigration, attrition, emigration, those not available for work at present, and retirement or other attrition. Parameters for the demand models include population size and characteristics, disease prevalence, level of need, and amount of service delivered by doctors and dentists (61). Baseline need was measured by types of care (acute, long-term or primary), and age sex subgroups. Population need was projected for each type of care using indicators such as number of general practitioner (GP) visits per type of care, or bed-days per type of care (61).

The CWI has adopted a need-based model where need was proxied by type of care. This approach assumes that 'type of care' appropriately reflects manpower requirements and that all care is in the 'formal' care sector. However, such a model cannot account for the multidisciplinary nature of patient care or for the complex determinants of the location of or patient placement for care (e.g., patients not discharged due to insufficient home care places or social services)

2.3.9 United States

The Health Resources and Services Administration (HRSA) and the National Center for Health Workforce Analysis of the US Department of Health and Human Services are the primary federal agencies for developing the tools to project the supply and demand for healthcare professionals in the US (62, 63). HRSA has released reports for doctors (by sub-specialty), registered nurses (RN), licensed practical nurses (LPN), pharmacy, dentistry, public health and clinical laboratory workforce (64). The stock and flow supply model parameters included licence renewal, retirement, death, disability, local and international graduates, productivity, career change and projected FTE. Specific to RNs, the model captures the progression from one educational level to another, and their interstate migration (65).

The demand model used a utilisation-based approach and included parameters such as service utilisation, demographics, insurance coverage/healthcare payment system, patterns of care delivery, technology, healthcare regulation, and workload measures such as inpatient days, visits, and nursing facility residents. Care delivery patterns were expressed as healthcare professional-to-population ratios by specialty and population segment defined by age, sex, geographical location, and insurance type. The demand model projected FTE's by service sector (65). The manpower gap between the supply and demand was expressed as an FTE ratio (65). The supply models used trend analysis and stock and flow methods. Supply model parameters included graduates, male-female ratio, death, retirement and projected FTE or FTE-to-population ratio.

HRSA has developed numerous models by healthcare professional groups and identified the core model parameters. The HRSA models could be improved by incorporating explicit measures of externalities in the model parameters.

2.4 Learning from commonly adopted technical approaches

Although a demand/utilisation-based approach was the most frequently used manpower projection method, need-based methods, trend analysis, and benchmarking (healthcare professional to population ratio) were also used. Demand/utilisation-based models for doctors, dentists, nurses and pharmacists project FTE based on service utilisation and have usually included the following parameters, hospital admissions and patient visits, utilisation weighted patient diagnosis, outpatient visits, treatment, population growth and age distribution, economic indicators, geographic factors, insurance status, and staffing intensity. For pharmacists the parameters have included the number of prescriptions filled, growth in prescription volume for pharmacists, direct-to-consumer marketing and Aggregate Demand Index (a measure of unmet demand at the population level). Many of the projection models were stratified by service sector. Data was derived from aggregate data from annual reports, historical utilisation data and doctor – population ratios. Model validity and reliability was compromised by data availability and quantity. A positive linear relationship between population and economic growth, healthcare utilisation and demand was assumed by most.

Model assumptions were often tested by scenario analysis including change in 1) supply (e.g. number of graduates, registered practitioners, or entrants to higher education, number of training places, migration, retirement rates, changes in funding, reimbursement and recruitment), 2) productivity and efficiency (activity rates), 3) population demographics, 4) burden of disease health and healthcare utilisation, 5) economic development, and 6) patient/staff satisfaction. The lack of normative standards defining work and productivity was a major impediment to workload analysis. Manpower requirements were most often expressed in FTE.

While methods for modelling manpower demand for other healthcare professionals (i.e., not doctors) are not as well developed, utilisation, service delivery, expected service growth and number of vacant positions were used to project FTE requirements. Some models based demand projections on subjective assessment of demand, workload and productivity. Scenarios, testing change in population demographics, service utilisation, service provision or practice structure, disease incidence and prevalence, and norms of care were used to assess the projection performance.

Existing supply models have used stock and flow methods to project headcount or FTE. These models have included parameters also used by supranational agencies (WHO and OECD) and national models. These included age, sex, number of graduates, number of registered doctors, attrition (retirement, immigration, or emigration), and practice location. Adjusted trend analysis and straight-line projections have been used for physiotherapist manpower supply projections. The models projected manpower requirements by headcount, FTE or by healthcare professional-to-population ratio.

Table 2.1 summarises projection methods, demand and supply parameters for manpower projection models by healthcare professionals (doctors, dentists, nurses, Chinese Medicine Practitioners (CMP), pharmacists (Pharm), chiropractors (Chiro), medical laboratory technologists (MLT), occupational therapists (OT), optometrists (Opt), physiotherapists (PT), radiographers (Radio), and dental hygienists (DentH). See **Appendix B** for the full list of healthcare manpower planning and forecasting publications.

Table 2.1 Projection methods, demand and supply parameters for manpower projection models by healthcare professionals

	Model methods	Demand parameters	Supply parameters
Doctors (11, 66-77)	Supply: stock and flow, trend analysis Demand: regression-based physician density model, demand/utilisation-based model, need-based model, benchmarking	Age, Gender, Population density, Consultation length, Number of consultations or procedures, Morbidity, Mortality, Life expectancy, Fertility rate, Literacy, GDP; GNI, Health expenditure, Insurance status, Epidemiology, Inputs of other types of professionals,	Age, Sex, Population growth, Retirement, Death, Migration, Re-entrants, Movement between occupations, Graduates, Work location, Working hours, Level of service, Intensity of work,
Dentists (78-91)	Supply: stock and flow Demand: demand/utilisation-based model, need-based model	Population projection, Income of population, Socio-demographic characteristics, Projected utilisation increase, Decayed, missing and filled teeth rates, Prostheses rates, Rates of edentulousness, Rates for other dental procedures, Dental attendance pattern, Patterns of disease, Dentist-to-population ratio	Retirement, Death, Graduates, Migration, Number of new dental schools, Number of other dental professionals, Population estimates, Gender ratio, Working hour, Productivity
Nurses (65, 92-111)	Supply: stock and flow, trend analysis, benchmarking Demand: benchmarking, demand/utilisation-based model, trend analysis, need-based model	Bed capacity/ occupancy rate, Working hours, Staffing intensity, Utilisation of services, Insurance status, Population growth and aging, Per capita income, Burden of disease and injury, Surgical intervention, Race/ethnicity classification, Area of practice, Nurse-to-physician ratio, Staff norms, Turnover rates, Vacancy rates	Graduates, Re-entrant, Retirement; Illness, disability and death, Working hour, Migration, Population, Education, Age, Sex, Career change, Maternity, Renewal rate
Chinese Medicine Practitioners	No specific published manpower planning and projection models		
Pharmacists (112-126)	Supply: stock and flow Demand: trend analysis, benchmarking, demand/utilisation-based model	Graduation rates, Population growth and aging, Expiring drug patents, Prescription volume, Role extension, Pharmacist-to-technician ratio, Pharmacist-to-population ratio, Direct-to-consumer marketing, Insurance coverage, Therapy improvement	Age, Male: Female ratio, Working hours, Graduates, Migration, Retirement, Death, Workload, Productivity.
Chiropractors (127-130)	Supply: stock and flow; supply description Demand: need-based model	Patient visits per week, Number of services per chiropractic user, Chiropractic use per capita, Change in technology, Change in patterns of the diseases, Prevalence of back and neck symptoms	Age, Sex , Education, Number of graduates, Geographic variation
Medical Laboratory Technologists (131,132)	Supply: trend analysis; stock and flow Demand: demand/utilisation model	Time units per activity, Number of laboratory tests per FTE, Population characteristics, Technology improvements	Number of graduates, Working hours, Examination pass rates, Field of practice, MLT post vacancy rate
Occupational Therapists (133-136)	Supply: stock and flow Demand: demand/utilisation model	Current OT employment data, Number of vacancies (in FTE), Hospital and home care average growth rate,	New graduates, Attrition and retention rate
Optometrists (137-141)	Supply: stock and flow	Diagnosis and service hours Population growth	Age, Sex, Number of registered optometrists, Local and non-local graduates, Mortality,

	Demand: trend analysis; demand/utilisation model		retirement, or emigration
Physiotherapists (142-145)	Supply: stock and flow Demand: trend analysis; need-based model	Population growth, Increase in personal healthcare expenditure, Personal health insurance, Number of in-patient, outpatient and home-bound Patient visits	Number of current vacant posts, Retirement and attrition, New graduates, New registrants, Registration renewals.
Radiographers (146,147)	Supply: stock and flow Demand: trend analysis; demand/utilisation	Service utilisation By procedures By modality, (e.g. CT, MRI, ultrasound and therapeutic procedures) Population demographics and growth	Age, Number of graduates, Retirement and other attrition, Training attrition, Working hours (full-time or part-time), Field of practice
Dental Hygienists	No specific published manpower planning and projection models		

2.5 Learning from local experience in workforce planning

2.5.1 Department of Health

The Department of Health (DH) has conducted Health Manpower Surveys (HMS) for healthcare professional groups with registration in Hong Kong since 1980. The surveys aim to provide up-to-date information on the characteristics and employment status of healthcare personnel working in Hong Kong. The data, compiled into aggregate health manpower statistics, aids the understanding the dynamics of healthcare professional manpower supply. However these are essentially repeated cross sectional surveys with no prospective predictive function or objective, thus cannot inform future needs without further analytical processing.

2.5.2 Hospital Authority

In Hong Kong, much of the current manpower planning and forecasting for public sector has been planned within the HA, which adopted an integrated approach in projecting its future healthcare workforce requirement. The process starts with an overall assessment on the future service demand which covers a comprehensive spectrum of HA services, ranging from in-patient, day-patient to outpatient, ambulatory and community services as well as clinical supporting specialty services. The service demand projection uses age- and specialty-specific service utilisation rates in a given year as the base year and took into account anticipated changes resulting from various factors. The HA model included population growth and ageing, changes in the service delivery model and utilisation pattern, medical technology advancement, and the development of new services.

To estimate the required doctor manpower, the projected service demand by specialty is translated into work-related time units (man-hours) for doctors. Together with respective specialty-specific clinical coordinating committees, the average time required for doctors to carry out other work-related tasks is estimated. Future doctor manpower requirement is then determined by assuming some specialty-specific parameters such as on- and off-site call, coaching, training and documentation, and community service. A similar work profile analysis is conducted for nurses in close collaboration with nurse representatives, and identified key nursing components of general and psychiatric work within different clinical settings.

Besides the additional demand generated by projected service growth, the future manpower requirement also considers replacement demand generated by staff turnover including retirement. Additional demand also takes into account manpower shortfall at the baseline. The HA manpower planning and projection model has provided a service level model, based on historical data. The model incorporates the impact of realised change in service delivery on future manpower requirements. While the HA provides a substantial proportion of in-patient and outpatient care to the population the model cannot represent all healthcare need (as proxied by utilisation) within the population. A comparison of the HA model and the territory wide model as presented in the report is not possible at this juncture.

2.5.3 Hong Kong Academy of Medicine

During the past decade, the Hong Kong Academy of Medicine, through the respective specialist Colleges, has reviewed medical manpower planning to determine the demand for different medical specialities and the requirements for training posts. Throughout the review a number of important externalities pertinent to manpower planning including the dynamics of the private and public interface, patient culture and expectations, and healthcare policy were identified. Individual colleges submitted estimates for manpower demand based on caseload or overseas benchmarks and provided input on the specific factors expected to influence future manpower need in their subspecialty (148). Individual colleges have found it difficult to project specialist manpower demand primarily due to difficulties in estimating the impact of the shift in practice location between the public and private sectors, medical tourism, changing technology, and areas of practice. The Academy acknowledges the limitation of assessing need from the medical perspective only and the difficulties in accurately determining demand, however, the recommendations put forward provide valuable input to manpower planning and forecasting in Hong Kong.

2.5.4 Independent manpower planning and policy reviews

The Business Professionals Federation of Hong Kong (BPF) healthcare manpower planning report of September 2010 recommends a more scientifically based and inclusive approach to manpower planning than what had been done previously (149). The report lists three essential planning ingredients for effective planning: 1) administrative data of past and present manpower resources, 2) research personnel equipped with skills and modelling tools to undertake dynamic projections, and 3) collaboration of all stakeholders.

In June 2012, HKGolden50 an independent not-for-profit research organisation, published their fourth report “How to Create A World-Class Medical System” with the aim to “alert our community that despite our World Class standard in Western and Chinese medicine our healthcare system is on the brink of breaking down due to insufficient hardware and personnel coupled with surging local and foreign demand for our quality medical services” (150). Based on HA data (i.e. public in-patient data only) the authors predicted a rapidly increasing (2% a year) shortage in doctors (150). Factors influencing this shortage are suggested to include 1) surging healthcare service demand deriving from population ageing, population growth, and medical tourism (demand for private healthcare from mainland China), and 2) stagnation supply due to retirement, declining competency due to the loss of senior staff, generation gap, feminisation of the work force, high entry barriers for overseas-qualified doctors, and insufficient support staff (nurses and administrative staff).

2.6 Implications for the Hong Kong manpower project

Many manpower-planning challenges have been previously identified in our review of work already completed. These include: 1) persistent manpower shortages and mal-distribution of the healthcare workforce, 2) population ageing, 3) rising incidence of chronic diseases, 4) lack of resources for medical training, 5) lack of cooperation within and between institutions, and 6) poor reliability and credibility of current manpower forecasting models.

The country level models identified lack consensus on the methodological approach for healthcare manpower planning and forecasting, and illustrated data-related problems including a lack of standardisation in variable parameterising; limited access to the quantity and quality of the data required; limited information on productivity, workload, and utilisation; and limited information on treatment efficacy and effectiveness. These models used routine administrative data (utilisation or financial data), or data from specialised surveys, and/or applied a predetermined set of assumptions in the demand/utilisation models.

Many country level models were deterministic and lacked the flexibility to examine the dynamic relationships between manpower supply and patient outcomes. In addition, the linear analysis adopted by many was problematic due to the underlying non-linearity of the data. More current manpower planning models used system dynamic methods, considered need, supply and demand simultaneously, projected manpower requirements from multiple perspectives and provided a more complete estimate of future manpower requirements. There was little evidence (in both qualitative and quantitative terms) of the impact (or evaluation) of these human resource-planning strategies on healthcare practice.

Models that did not specify benchmark standards or methods to determine the relationship between the volume of service/ number of patients and the number of staff were unable to robustly estimate the number of staff required for specific activities. Induced demand (as measured by utilisation data and doctor defined diagnosis in demand models) was a characteristic problem of manpower planning and forecasting and was a major limitation of the current country level manpower planning and forecasting models world-wide and locally.

In Hong Kong, population ageing, rising incidence of non-communicable disease, and historical healthcare utilisation patterns is related to rapidly increasing demand for healthcare service. Elsewhere, changing patterns of referral, location of service delivery (public and private), technology, scope of practice (including complementarity and substitution between healthcare professionals), feminisation of the workforce and healthcare policy (such as extended personal insurance coverage, increased in public healthcare benefits) and service delivery regulation (such as the recommendations of the Review Committee on Regulation of Pharmaceutical Products) have been implicated with increased demand for healthcare service (151). The increased demand arising from the mainland visa-free tourist policy are expected to increase future manpower demand. Economic and healthcare policy (i.e. Closer Economic Partnership Arrangement II (CEPA)), changing population demography, inter-regional and inter-sectoral (public/private) movement of healthcare professionals and patients, and medical tourism are expected to increase future healthcare demand and further complicate manpower projection.

Manpower projection is a highly data intense activity. Although public sector in-patient and outpatient data suitable for manpower projections is readily available, a substantial proportion of patient care occurs in the private sector, where data is less complete, more complex or simply unavailable. Such an environment necessitates manpower projection models that are adaptable to changing parameters and model structures.

3 Projecting demand

The overall model for Hong Kong manpower projection comprises two sub models, the utilisation model and the supply model. Building on an endogenous, historically-informed base case scenario (where current utilisation (proxying demand) and supply are assumed to be in equilibrium), this model can be adopted to adjust for the impact of externalities such as: Special Scheme on Privately Owned Sites for Welfare uses including Residential care services for the elderly, Day care service for the elderly, Residential care service for persons with disabilities and Day care/vocational rehabilitation service for persons with disabilities new hospitals, and the Voluntary Health Insurance Scheme and policy options such as HA service enhancement. The difference between the demand and supply projections (in terms of total FTE numbers, year-on-year and annual incremental FTE from 2012 -2041) is the manpower 'gap' or 'surplus/shortfall'.

3.1 Modelling demand

After a thorough literature review, assessing the suitability to the local context and exploratory analyses with the various possible projection modes, three approaches for projecting healthcare utilisation are shortlisted for further consideration, the 'empirically observed historical' (EOH), the 'macroeconomic scenario driven' (MSD) and the 'Andersen-type' (Andersen) approach within a 'top down' and 'bottom up' framework (Figure 3.1). Given the lack of required data elements for the Andersen approach, namely detailed individual-level data on predisposing and enabling factors as well as panel studies locally, the two 'top down' approaches are eventually executed.

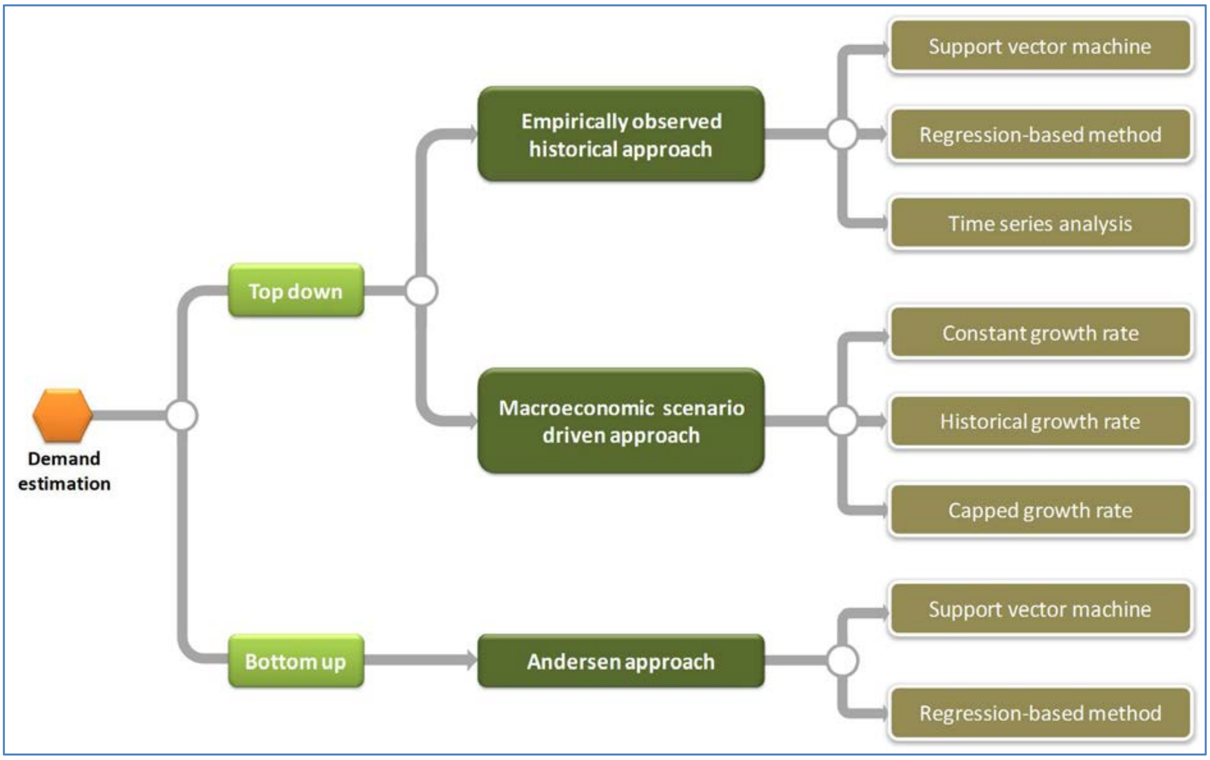

Figure 3.1 Approaches to estimating demand

3.1.1 Empirically observed historical (EOH) approach

The EOH projection model expresses utilisation as the product of population *P* and utilisation rate *R*:

Utilisation z(*y*) at year $y = \sum_a \sum_s P(a,s,y) \times R(a,s,y)$

where *P*(*a*,*s*,*y*) is the population age-, sex-specific groups (*a*,*s*) at year *y*, and R(*a*,*s*,*y*) is the utilisation rate by age-, sex-specific groups (*a*,*s*) at year *y*. Census and Statistics Department population projections are used for the projected *P*(*a*,*s*,*y*), historical data inform the computation of *R*(*a*,*s*,*y*).

3.1.1.1 Support vector machine (SVM)

SVM[2] is used to estimate the utilisation rate of each age-, sex-specific group at a given year. SVM is a kernel-based neural network that maps an input x to an output y where w_i is the weight and B is the bias term by the following expression:

[2] Artificial neural networks (ANN) and specifically the Support Vector Machine (SVM) used for these projections are able to predict the complex relationships driving utilisation. Support vector machine (SVM) is a supervised learning method that analyses data and recognizes data patterns in the historical data. As such this artificial intelligence predicts for each given variable the corresponding outcome. SVM was chosen for the projection as it will 'evolve' an optimal structure and estimate the service utilisation of a given individual based on characteristics such as age, and sex.

$$y = \sum_i w_i \kappa(\mathbf{x}_i, \mathbf{x}) + B$$

As compared with linear and exponential regression models, SVM has the flexibility to 'evolve' an optimal structure according to historical data. A Gaussian radial basis kernel i.e. $\kappa(\mathbf{x}, \mathbf{y}) = \exp(C\|\mathbf{x} - \mathbf{y}\|)$ is used as it is the 'universal approximator'. The structure is well regularised, and the generalisation ability of the network is maximized.

SVM *learn* the utilisation rate pattern from historical data expressed as:

$$\begin{bmatrix} a_1, s_1, y_1 | r_1 \\ a_2, s_2, y_2 | r_2 \\ a_3, s_3, y_3 | r_3 \\ \vdots \end{bmatrix}$$

where r_i is the utilisation rate of age-, sex-specific group (a_i, s_i) at year y_i. A specific network construction algorithm is designed to evolve the structural parameters $\{w_i\}$ and B. The trained SVM projects the utilisation rate $R(a,s,y)$ of an age-, sex-specific group (a, s) at projection year y = 2012, 2013, …. using the following equation:

$$R(\text{a,s,y}) = \sum_i w_i exp\left(-\frac{(a - a_i)^2 + (s - s_i)^2 + (y - y_i)^2}{2\sigma^2}\right) + B$$

The utilisation volume at year y is computed as:

$$\sum_{a,s} R(\text{a,s,y}) \times P(\text{a,s,y})$$

where $P(a,s,y)$ is the population size of the age-sex group (a,s) at year y.

3.1.1.2 Regression-based method (RBM)

In the RBM approach, $R(a, s, y)$ is estimated by Poisson regression, which assumes:

$$N(a, s, y) \sim Poisson(O(a, s, y)R(a, s, y))$$

$$\log R(a, s, y) = \alpha(a, s) + \beta(a, s)y$$

where $N(a,s,y)$ denotes the utilisation volume and $O(a,s,y)$ is an offset term in age group a, sex s, and year y. For the projection of all utilisation measures except average length of stay, the population of age group a, sex s, and year y are used for the offset term $O(a,s,y)$. For the projection of average length of stay, the offset term is the number of discharges. Since $\log R(a,s,y)$ is a linear function of y, $R(a,s,y)$ is an exponential function of y all age- and sex-specific demand variables are included in the Poisson regression. For utilisation measures where there are clear differences in slopes across age-, sex-specific groups (including public and private day case, acute care in-patient discharge and average length of stay (ALOS), as well as HA general outpatient (GOP), specialist outpatient (SOP), accident and emergency (A&E), and private outpatient visits), the projections have age-, sex-specific intercepts and slopes. For all other utilisation measures (public long stay discharge and average length of stay, as well as all DH service visits), the age-, sex-specific intercepts and slopes are constrained to be the same across age and sex groups.

In sensitivity analyses, the Poisson regression projections are compared with projections based on a linear trend. As utilisation rates in linear trend projections may drop below 0, linear projections are used only for utilisation rates that show an increasing trend. The utilisation rate increase is assumed to be the same across all age-, sex-specific groups for SOP, A&E, private outpatient, and all DH visit rates projections lest projections for individual age and sex groups reach zero.

A weighted linear regression is deployed, where the population in age group a, sex s, and year y are used as weights (i.e., $P(a,s,y)$). The following function is minimised with respect to $\alpha(a,s)$ and $\beta(a,s)$.

$$\sum_{a,s,y} P(a,s,y)(R(a,s,y) - \alpha(a,s) - \beta(a,s)y)^2$$

Projections of rates are given as:

$$\hat{R}(a,s,y) = \alpha(a,s) + \beta(a,s)y$$

The weights are needed to ensure the estimated age, sex, and year-specific rates $\hat{R}(a, s, y)$ are consistent with the observed rates $R(a, s, y)$.

3.1.1.3 Time series approach

As the elderly and rehabilitation service provision is land-driven, a time-series analysis is used to project the historical growth patterns for elderly and rehabilitation services assuming growth trends $u(y)$ as follow:-

Linear trend

Where the number of places / cases is a linear function of projection year y:-

$$u(y) = ay + b$$

Exponential decay trend

Where the number of applications is expected to decrease exponentially:-

$$u(y) = we^{-\alpha y} + c$$

Constant trend

Where service provision is stable and held constant as at the baseline year:-

$u(y) = u_0$

3.1.1.4 Macroeconomic scenario driven (MSD) approach

As in the EOH-RBM approach, the MSD approach expresses utilisation as the product of population P and utilisation rate R:

Utilisation $z(y)$ at year $y = \sum_a \sum_s P(a, s, y) \times R(a, s, y)$

where $P(a,s,y)$ is the age-, sex-specific population (a,s) at year y, and $R(a,s,y)$ is the age-, sex-specific utilisation rate (a,s) at year y. Population projections of the Census and Statistics Department are used for $P(a,s,y)$. $R(a, s, y)$ and estimated as follows:-

$$R(a, s, y) = R(a, s, 2011) \times (1 + x)^{y-2011}$$

Three methods (constant growth, historical growth, and capped growth) are used to calibrate healthcare utilisation trends against observed data.

3.1.1.5 Constant growth rate

The constant growth rate method sets 'excess healthcare price/cost inflation'[3] growth at 0.2% public sector and 1% for the private sector, consistent with the international literature and to a previous local exercise (152). The public sector growth rate for each variable is benchmarked to the OECD (1999)(153). As the OECD reports utilisation growth rates of 0.4% per year, the model assumes a growth rate of 0.2% (154) because half of the growth is due to the net growth in the utilisation rate while the other half is assumed to be due to demographic changes.

Private sector growth rates are benchmarked to OECD (1999)(153) data for the United States and Switzerland, as these two countries predominantly provide healthcare in the private, albeit regulated, sector. The OECD reports an annual growth of 2.7% and 2.4% for the United States and Switzerland respectively. As the healthcare in Hong Kong is equally shared between the public and private sector, the utilisation growth rate in the private sector is assumed to be 1% (154).

3.1.1.6 Historical growth rate

For the historical growth rate method, 'excess healthcare price/cost inflation' x is estimated from the public and private hospital in-patient discharges and outpatient visits in Hong Kong. To estimate x, the following function is minimised:

$$\sum_{y} |N(y) - z(y)|$$

where $N(y)$ is the utilisation volume (number of public and private sector in-patient discharge and outpatient visits) and $z(y)$ is the estimated utilisation volume for that year:

$$z(y) = \sum_{a} \sum_{s} P(a, s, y) \times R(a, s, y)$$
$$R(a, s, y) = R(a, s, 2011) \times (1 + x)^{y-2011}$$

[3] The 'excess healthcare price/cost inflation' method is based on the United Kingdom Treasury's Wanless projection method which requires health expenditure to be broken down by age, sex, unit cost and activity level (i.e. volume in terms of healthcare utilisation). The projections take into account aspects of medical inflation (that is medical inflation over and above per capita Gross Domestic Product growth), changes in the utilisation of healthcare services as a result of demographic change, and total health care expenditure (activity levels multiplied by projected unit costs). This comprises two components, medical price increase and per capita volume growth, according to Huber's review of health expenditure among OECD countries in 1999.

3.1.1.7 Capped growth rate

As it may be inappropriate to assume ever exponentially increasing utilisation rates, the capped growth rate method is applied to the projection of discharge rates and outpatient (SOP and GOP) visit rates, such that rates would not indefinitely grow exponentially as follows:

$$R(a,s,y) = R(a,s,2011) \times \underbrace{\left(\frac{w}{1+e^{-\alpha(y-y_0-\mu)}} + B\right)}_{sigmoid\ function}$$

where $R(a,s,2011)$ is the age-, sex-specific utilisation rate for the baseline year 2011.
For average length of stay projections, a biased exponential function is used rather than the sigmoid function to prevent the projection falling below zero.

$$ALOS(a,s,y) = ALOS(a,s,2011) \times \underbrace{e^{-\alpha(y-\mu)}}_{biased\ exponential\ function} + B$$

The parameters *w*, α, μ and *B* are estimated by optimising the objective function:

$$\sum_{y} |N(y) - z(y)|$$

as in the historical growth rate model.

3.1.2 Adjusting for under-reporting

THS under-reporting rates for outpatient visits for the public and private sector are estimated for the THS 2002, 2005, 2008, and using routine HA and private hospital outpatient visits data (Figure 3.2). Due to data unavailability, estimates of under-reporting rates for private sector outpatient visits is not possible. Private sector under-reporting rates are assumed to be the same as for HA outpatient visits.

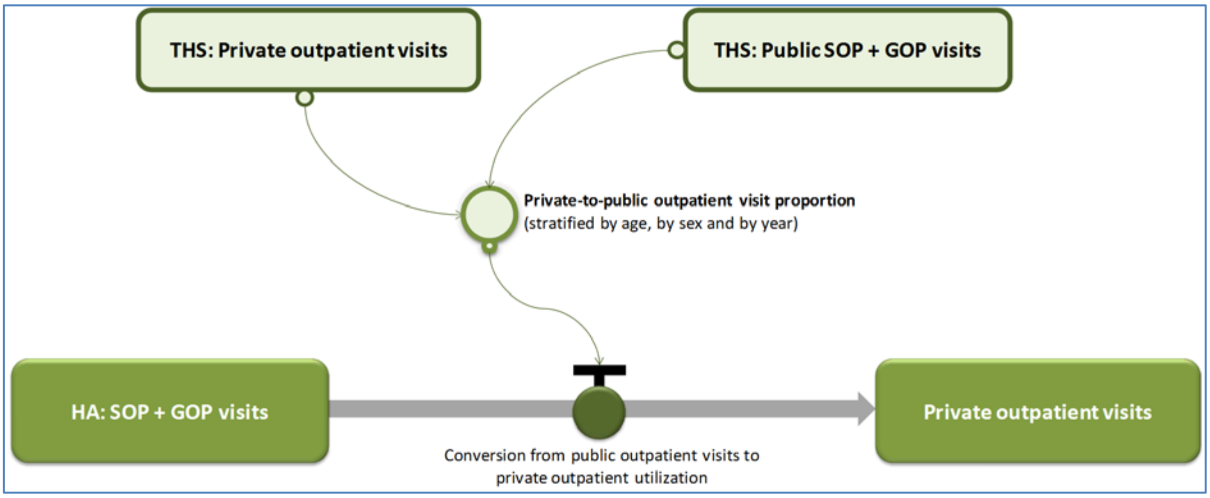

Figure 3.2 Under-reporting adjustment of THS outpatient visit data

3.1.3 Capping rates

The RBM gives exponential rate increases across all utilisation variables. This leads to projections that are too extreme to be realistic beyond the first few years. To address this problem, age-, sex-specific utilisation rates are allowed to continue until 2016 after which they are held constant (i.e. capped) for the rest of the projection period. The discharge and outpatient visit rate caps are benchmarked to the historical OECD utilisation trend data (OECD 2012) (154).

To set the discharge rate cap, the current OECD acute care in-patient discharge rate for Hong Kong (178 discharges/1000 person-year (152)) is compared to OECD individual country trends (Figure 3.3). Hong Kong discharge rate increase is benchmarked to the 90th percentile of the 2011 OECD countries discharge rate (237 discharges/1000 person-year) (representing an average discharge rate increase of 33%). Based on historical data Hong Kong will reach this estimated discharge rate by 2016, after which the discharge rate increase is capped.

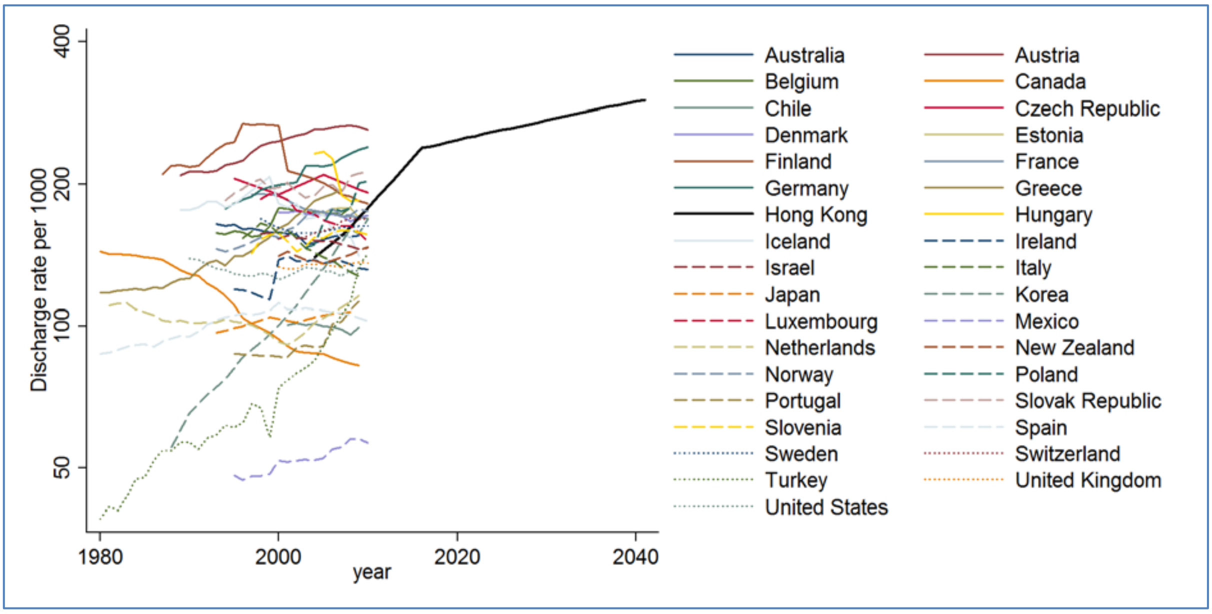

Figure 3.3 Comparison of Hong Kong and OECD acute care in-patient hospital discharge rates (152,153)

Similarly for outpatient visit rates, the doctor visit rate as published by the OECD for HK (2011) (11.2 visits per person-year (152)) is benchmarked against OECD individual country trends (highest rate 13.1 visits per person per year in Japan) (Figure 3.4). Based on this comparison, Hong Kong outpatient visit rates are expected to increase by 17% and will reach this target by 2016. The outpatient visit rate is capped after 2016.

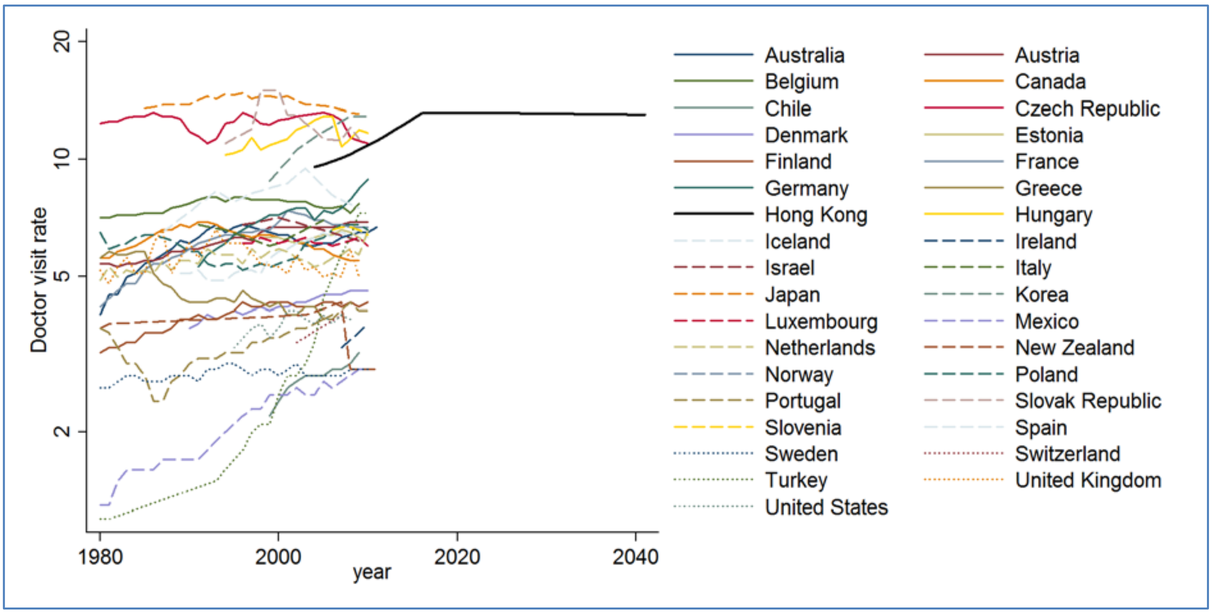

Figure 3.4 Comparison of Hong Kong and OECD doctor outpatient visit rates (152,153)

3.2 Model comparison

The top down methods (EOH and MSD), with relatively fewer data requirements, are based on the expectation that simple, aggregate models provide more reliable and reproducible healthcare utilisation projections. Further consistent, comprehensive data (number of observations and data-points) are available for the public sector. Much less reliable data are available for the private sector. The performance of a model is represented by the sum of absolute rate error $E(\theta, u)$:

$$E(\theta,u) = \sum_{a,s,y} \left| \widetilde{M_u}(a,s,y|\theta) - R_u(a,s,y) \right|$$

where $E(\theta, u)$ is the sum of absolute rate error of model θ ∈ {EOH-SVM, MSD-constant growth rate, MSD-historical growth rate} on utilisation rate *u*

$\widetilde{M_u}(a,s,y|\theta)$ is the estimated utilisation rate on *u* of age-sex group (*a*,*s*) at year *y* by model θ

$R_u(a,s,y)$ is the actual utilisation rate on *u* of age-sex group (*a*,*s*) at year *y*.

Note that the index *y* in the formulate of $E(\theta, u)$ has different range for different utilisation measures: $y \in \{2005, 2006, \ldots, 2011\}$ for public sector and private outpatient utilisation; and $y \in \{2007, 2008, \ldots, 2011\}$ for private sector inpatient utilisation. Table 31 lists the estimation error of EOH-SVM, MSD-constant growth rate and MSD-historical growth rate. The EOH-SVM models give a better model fit than the MSD models. The EOH-SVM estimation errors are smaller than those for the MSD-constant growth or MSD-historical growth rate models.

Table 3.1 Comparison of EOH-SVM, MSD-constant growth, MSD-historical growth rate estimation errors

	EOH-SVM	**MSD – constant growth rate**	**MSD – historical growth rate**
Day case discharge rate (public)	0.93	7.56	1.53
Acute care in-patient discharge rate (public)	0.82	3.83	2.05
Acute care in-patient bed day rate (public)	7.29	44.65	17.19
Long stay discharge rate (public)	0.03	0.08	0.05
Long stay bed day rate (public)	11.09	28.42	20.21
SOP visit rate	3.67	8.09	8.08
GOP visit rate	4.04	16.95	10.06
A&E attendance rate	2.26	5.30	4.69
Day case discharge rate (private)	0.18	0.57	0.48
Acute care in-patient discharge rate (private)	0.11	0.42	0.33
Acute care in-patient bed day rate (private)	1.06	2.45	2.28
Private outpatient rate	99.03	252.69	251.94

In a sensitivity analysis, as would be expected, the EOH-RBM linear based model gives projections that are less steep than the Poisson model (which assumes an exponential trend) however, the data do not support a linear trend more than an exponential trend. The mean squared error is smaller for most utilisation measures projected by the RBM-Poisson model (Table 3.2). To avoid negative values, age-, sex-specific utilisation measures in the RBM linear model, share the same intercepts and slopes.

Table 3.2 Comparison of the linear and exponential RBM utilisation projections mean squared error (MSE) for selected demand/utilisation variables.

Demand/utilisation variables	Natural scale		Log scale	
	Linear	Exponential	Linear	Exponential
Public day cases	25.8	18.0	0.0038	0.0026
Public specialist outpatient visits	700	522	0.0014	0.0007
Public general outpatient visits	1189	830	0.0038	0.0017
Accident and Emergency visits	165.4	125.8	0.0021	0.0016
Private day cases	1.63	1.76	0.0029	0.003
Private acute care in-patient discharges	6.13	6.69	0.0028	0.0013
Private outpatient visits	771405	561993	0.032	0.026
DH Student and child services	1022	982	1.21	0.09
DH Port Health Office	0.20	0.18	0.18	0.05

SVM models have the ability to generalize, learn from examples, adapt to situations based on historical data and generalize patterns from historical data in response to unknown situations. SVM implicitly detects complex nonlinear relationships between independent and dependent variables. When responding to nonlinearity between the predictor variables and the corresponding outcomes, the model automatically adjusts its structure to reflect these nonlinearities. The predictor variables in SVM undergo multiple nonlinear transformations and can thereby potentially model much more complex nonlinear relationships than RBM.

Regression models can also be used to model complex nonlinear relationships. However, these models require an explicit search for these relationships by the model developer and these may not be known or well understood. Appropriate transformations may not always be available for improving model fit, and significant nonlinear relationships may go unrecognized by model developers.

When complex data and relationships are involved, as compared to RBM, SVM would in theory at least, and empirically shown by the model fit statistics above, provide a more robust projection outcome, more flexibly integrates complex data into the model, and is not dependent on a pre-determined hypotheses about the relationships between model variables. For these reasons, the EOH-SVM approach has been used for all model projections in the report.

Support vector machine (neural network analysis), time series, and stock and flow method, are variously deployed to project the required number of healthcare professionals as a function of healthcare demand/utilisation and healthcare professional supply to 2041. The projections are stratified by service type (in-patient, outpatient, elderly and rehabilitation services) and by service location (public or private sector) as appropriate.

4 Projecting demand

The overall model for Hong Kong medical laboratory technologist manpower projection comprises two sub models, the utilisation model and the supply model. The difference between the demand and supply projections (in terms of total FTE numbers, year-on-year and annual incremental FTE from 2012 -2041) is the manpower 'gap' or 'surplus/shortfall'.

4.1 Parameters for medical laboratory technologist demand model projections

The demand projection considers population growth projections, historical healthcare utilisation volumes for 2 sectors and 4 settings and the number of students in the academic sector (Figure 4.1). As the test codes in the HA Laboratory Information System (LIS) are not standardized and there are no standardized tools for workload measurement, only aggregated HA laboratory data (2005 – 2013) by lab category and institution are used for the demand projections. For DH, aggregated number of laboratory tests (2005-2013) are used for the projections. For the public sector model, only data from 2005 are used as the data prior to these years would have been unduly influenced by organisational change within the HA and by the SARS epidemic. For the academic sector, the number of students enrolled in MLT training programmes. For the private sector, aggregated number of private hospital discharges (2007-2011) and private clinic/laboratory examinations (THS 2008) are available for the healthcare utilisation projections.

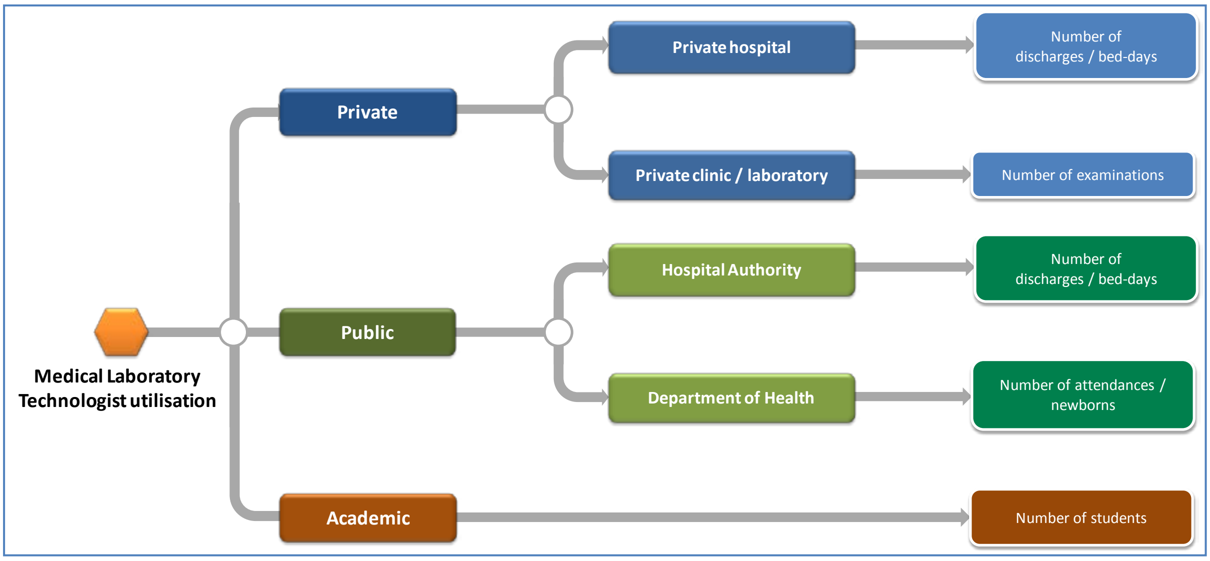

Figure 4.1 Flow diagram of medical laboratory technologist utilisation in Hong Kong

Table 4.1 specifies the setting, variables, parameterisation and data sources.

Table 4.1 Demand model variables, parameterisation and data sources

Variables	Parameterisation	Data source
Population to be served		
Resident population	Age- sex-stratified[2]	C&SD 1999 through 2011
Population forecast	Age- sex-stratified[2]	C&SD population projections 2012 - 2041
Public sector		
In-patient bed-days In-patient discharge Outpatient visits	Age- sex-stratified[2]	HA 2005-2013
Number of laboratory tests	Age- sex-stratified[2]	HA 2013
	Aggregated	HA 2005-2013 DH annual report 2005 -2013
Private sector		
Number of examinations (private clinics)	Age- sex-stratified[2]	THS 2008
Number of discharges (private hospital)	Age- sex-stratified[2]	Private hospital discharge record 2007-2011
Academic	Number of students	UGC records 2004-2013

4.2 Demand indicators

4.2.1 Medical laboratory service utilisation - Public sector

4.2.1.1 Hospital Authority

The HA medical laboratory technologist demand projection is utilisation-based where utilisation is proxied by the number of laboratory tests.

$$\begin{aligned} &Number\ of\ MLT\ FTEs\ in\ HA\ (F_{HA}) \\ &\quad = Number\ of\ laboratory\ tests\ (T_{HA}) \\ &\quad \times\ Number\ of\ MLT\ FTEs\ per\ laboratory\ test\ (\alpha_{HA}) \end{aligned}$$

As each type of test service has its own pattern and uses different MLT manpower resources demand is further stratified by test type as follows:-

$$F_{HA} = \sum_i T_{HA}^i \times \alpha_{HA}^i$$

where i is the laboratory test index (i.e. i = 1 for ‘Haematology’, i = 2 for ‘Blood banking’, i = 3 for ‘Microbiology’, i = 4 for ‘Histopathology / Cytology’, i = 5 for ‘Chemical pathology’, i = 6 for ‘Immunology’ and i = 7 for ‘Other pathology’),

T_{HA}^i is the number of the laboratory tests and

α_{HA}^{i} is the number of MLT FTEs per laboratory test.

As the age-, sex- specific attendance volume (and hence the attendance rate) is available only at 2013, the age-, sex- specific attendance volume for the aggregated attendance volume (2005 and 2012) are approximated.

The historical and projected age-, sex- specific HA acute care inpatient bed-days, acute care inpatient discharges, day case discharges and specialist outpatient visits, all of which increase sharply throughout the projection, are shown in Figure 4.2, 4.3, 4.4 and 4.5 respectively.

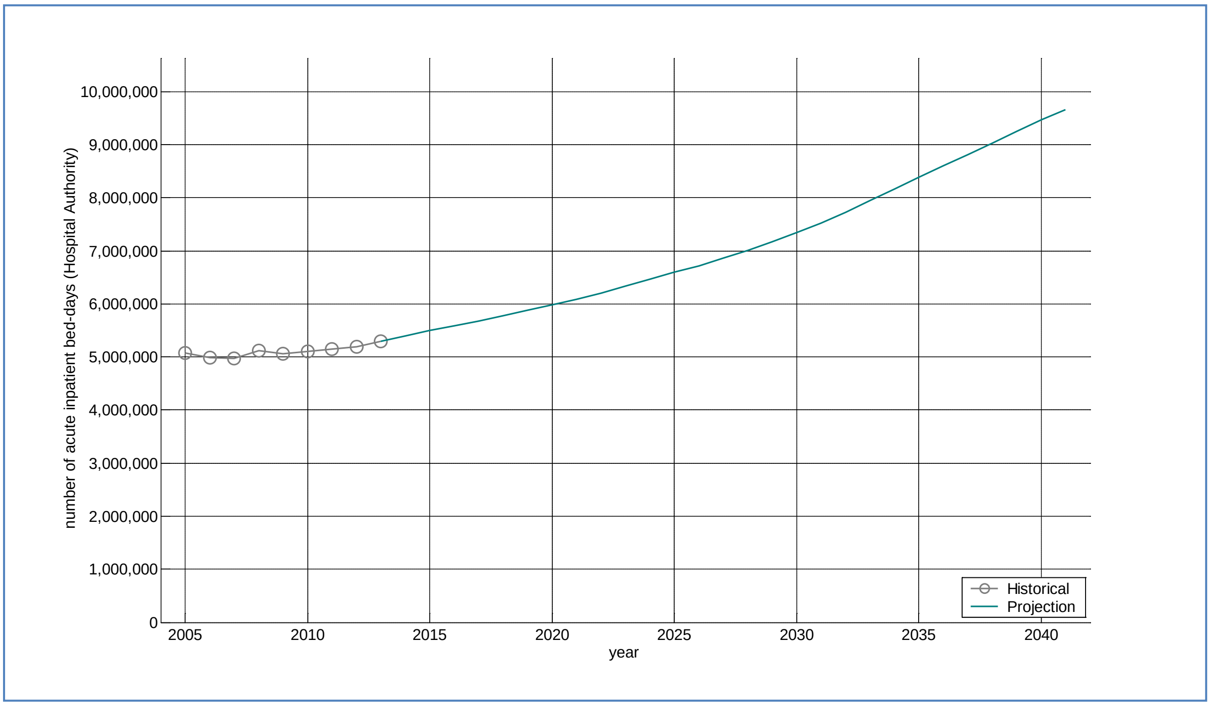

Figure 4.2 Historical and projected HA acute care inpatient bed-days

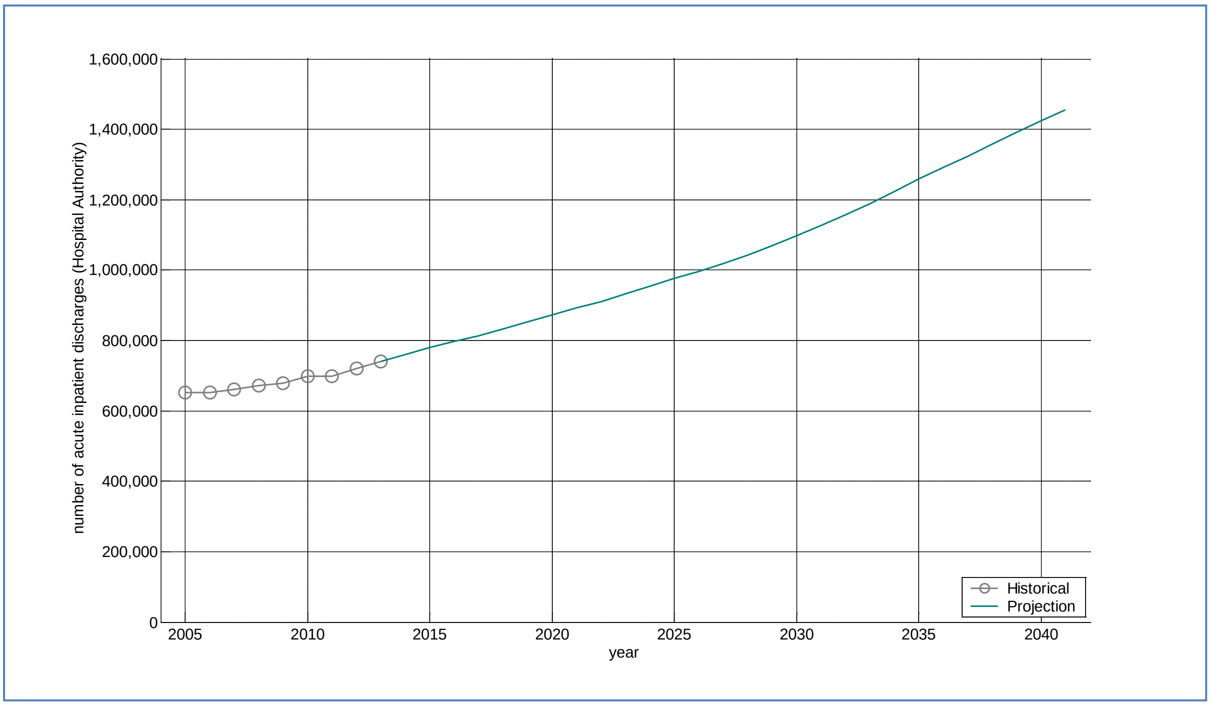

Figure 4.3 Historical and projected HA acute care inpatient discharges

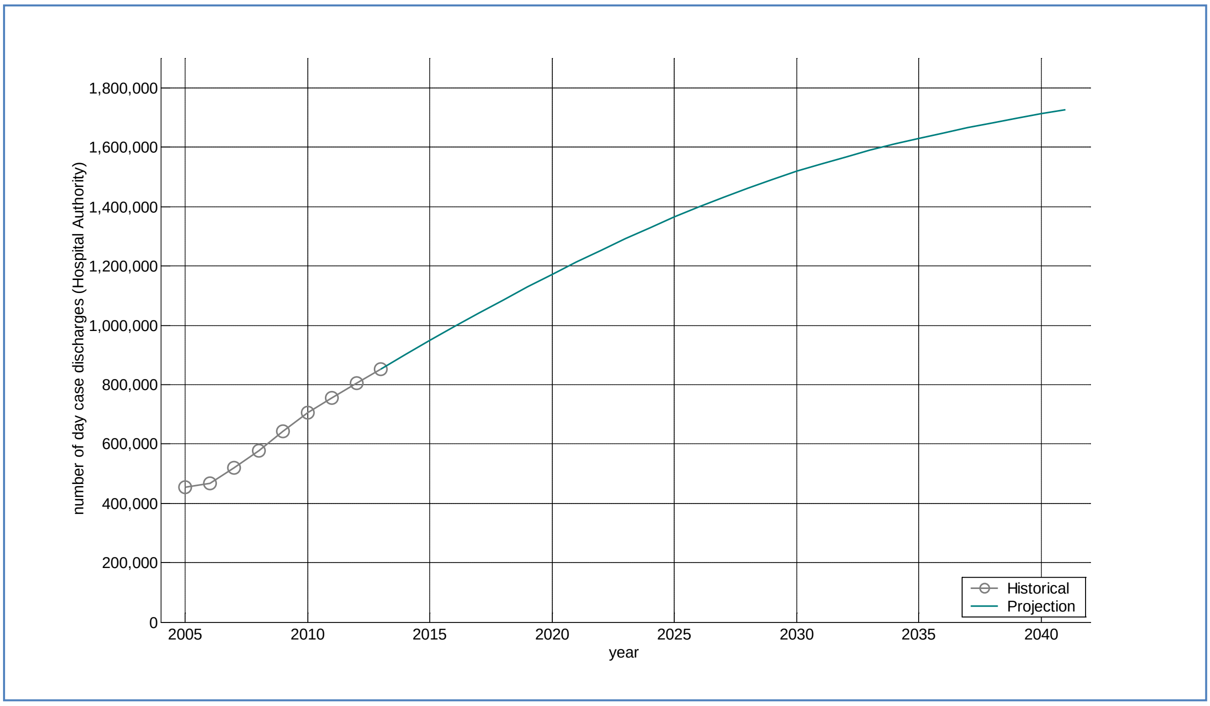

Figure 4.4 Historical and projected HA day-case discharges

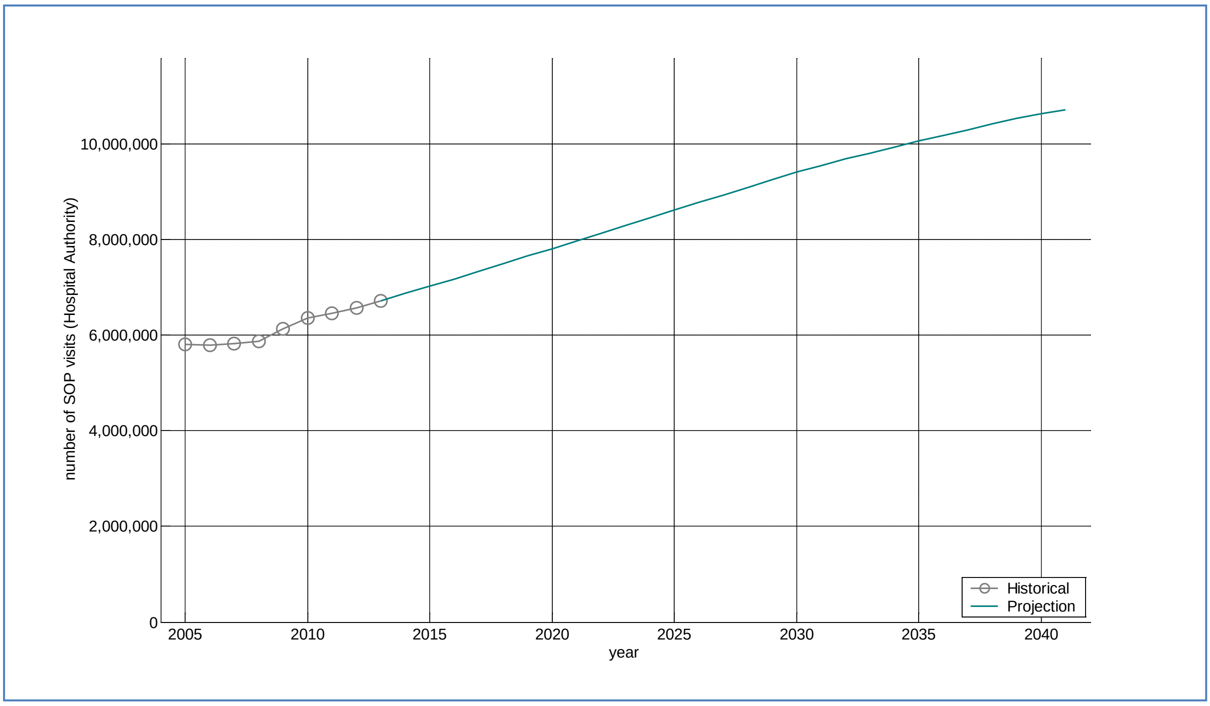

Figure 4.5 Historical and projected HA specialist outpatient visits

Whereas the total number of tests in all categories of tests are projected to increase sharply (Figures 4.6, 4.8, 4.10, 4.12, 4.14, 4.16 and 4.18), the number of tests per case for haematology, blood banking, histopathology/cytology, chemical pathology are projected to increase slowly (Figures 4.7, 4.9, 4.13, and 4.15), the number of tests per case for immunology and other pathology increase and then plateau (Figure 4.17 and 4.19) and the number of tests per case for microbiology remain flat (Figure 4.11)

Haematology

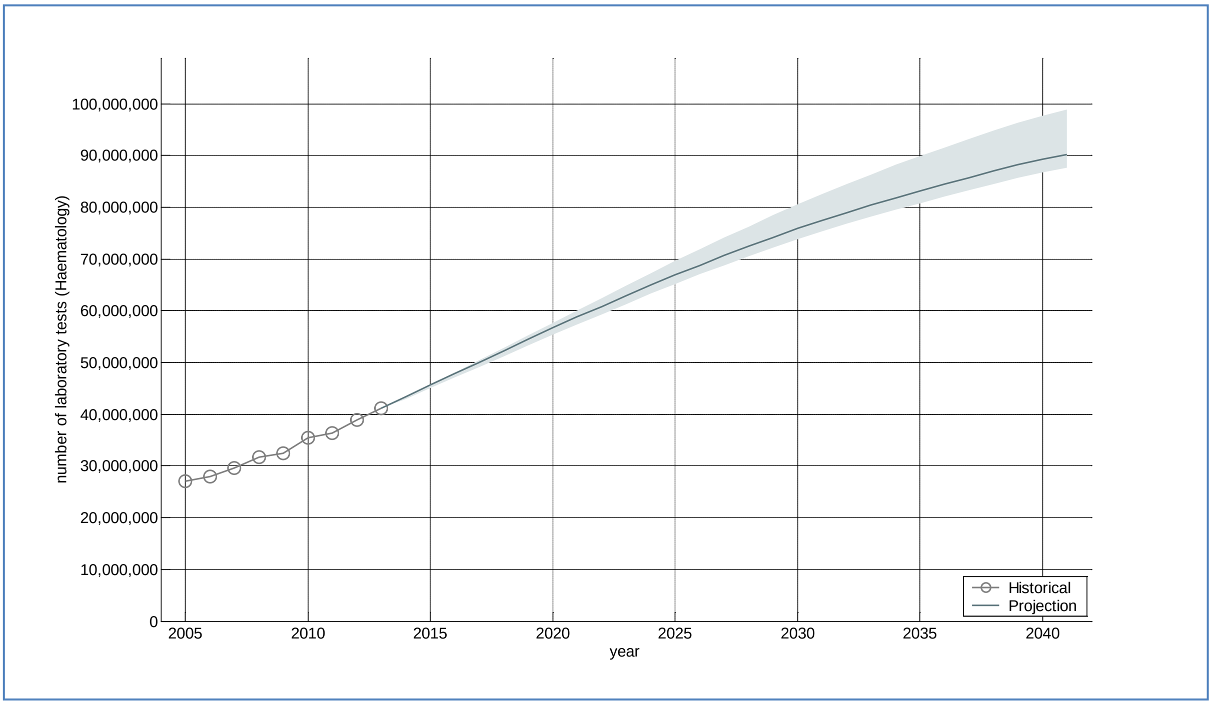

Figure 4.6 Historical and projected number of laboratory tests: Haematology

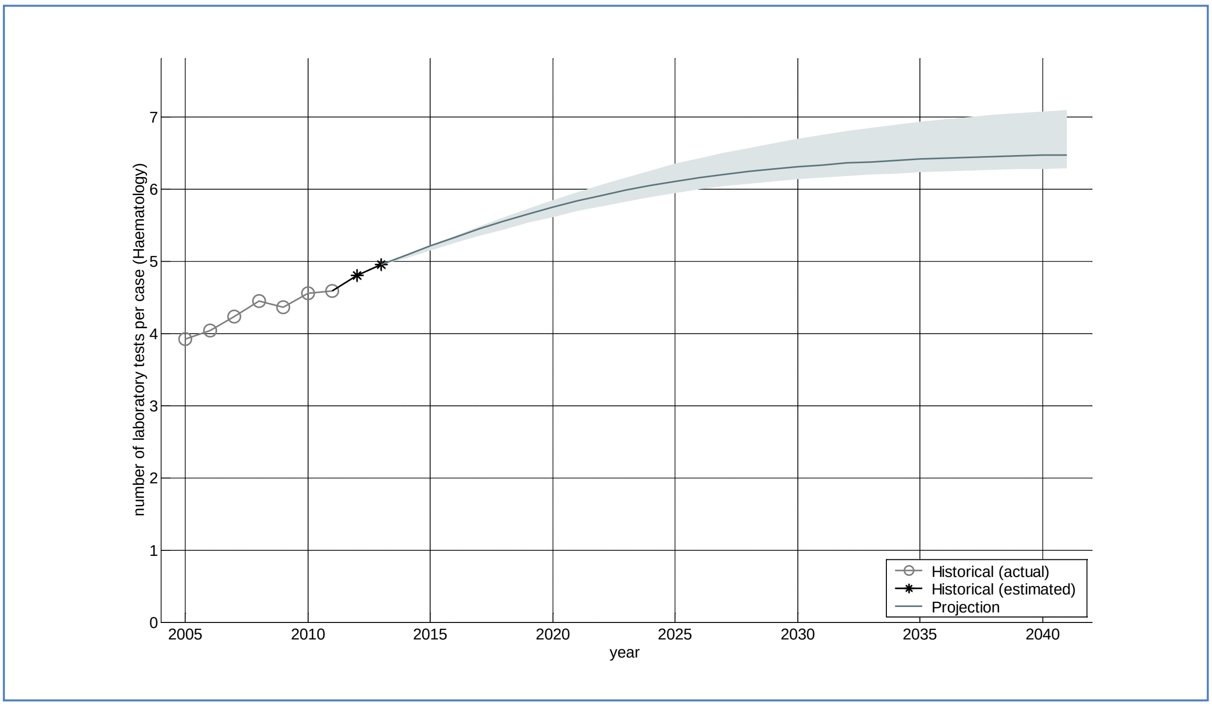

Figure 4.7 Historical and projected number of laboratory tests per case: Haematology

Blood banking

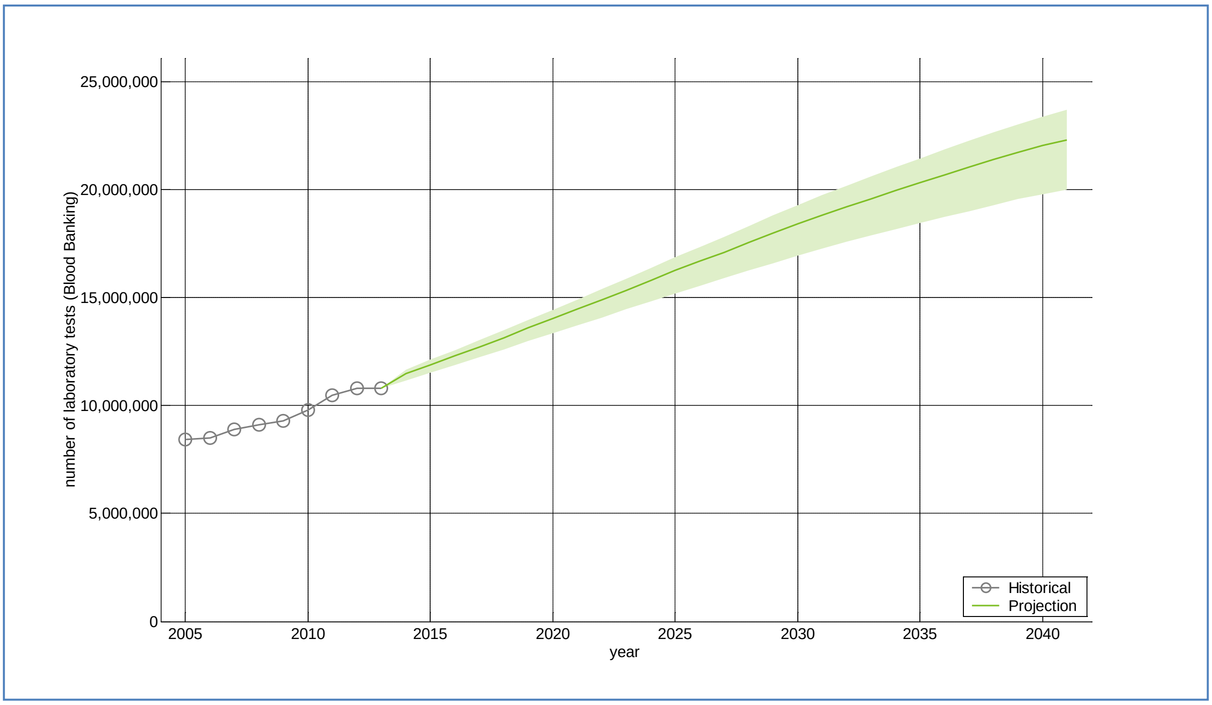

Figure 4.8 Historical and projected number of laboratory tests: Blood banking

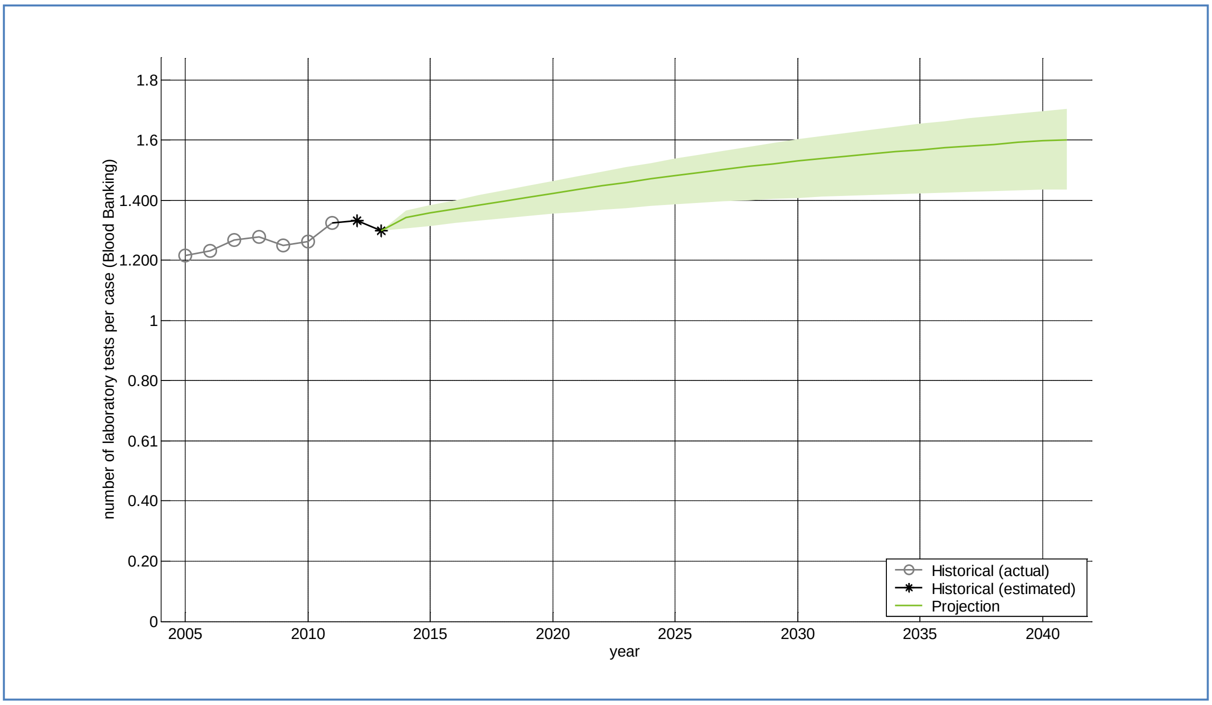

Figure 4.9 Historical and projected number of laboratory tests per case: Blood banking

Microbiology

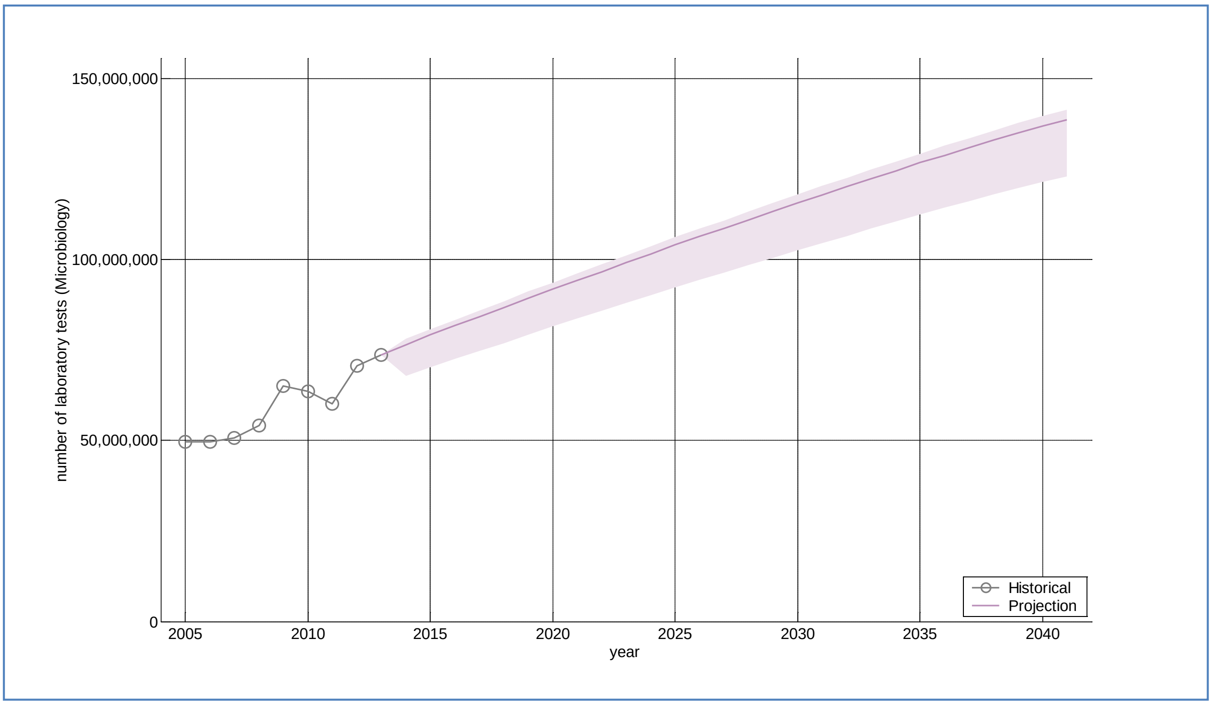

Figure 4.10 Historical and projected number of laboratory tests: Microbiology

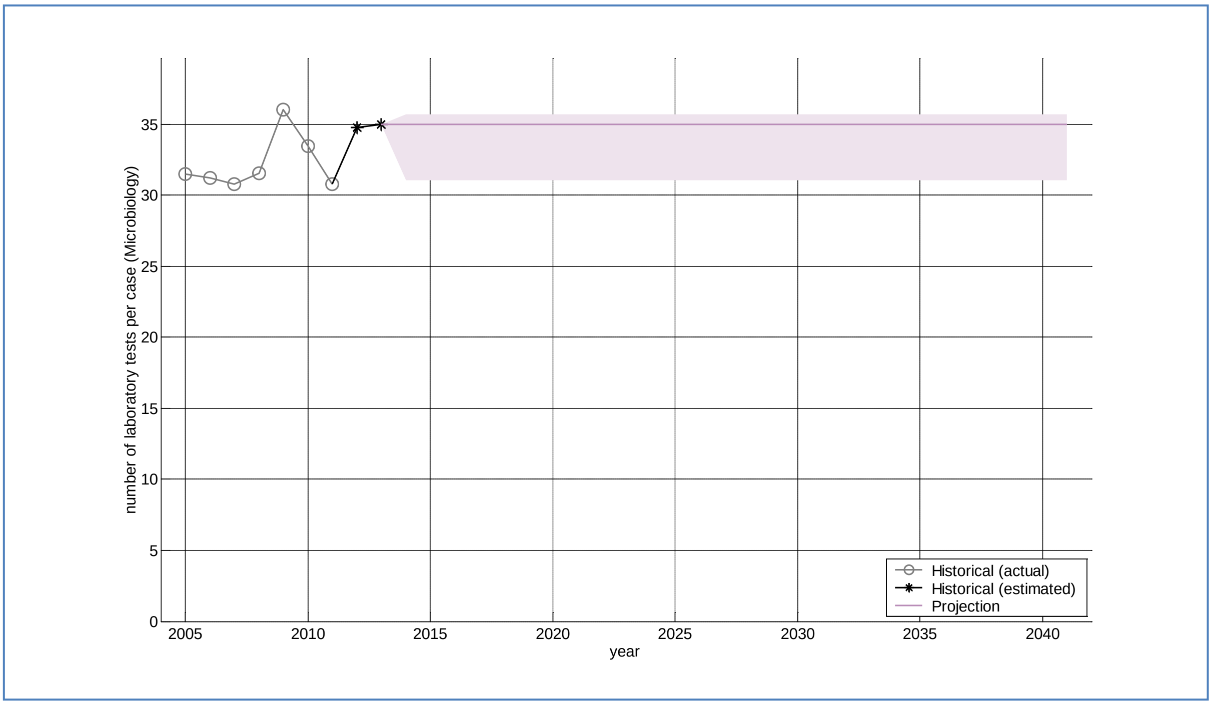

Figure 4.11 Historical and projected number of laboratory tests per case: Microbiology

Histopathology / Cytology

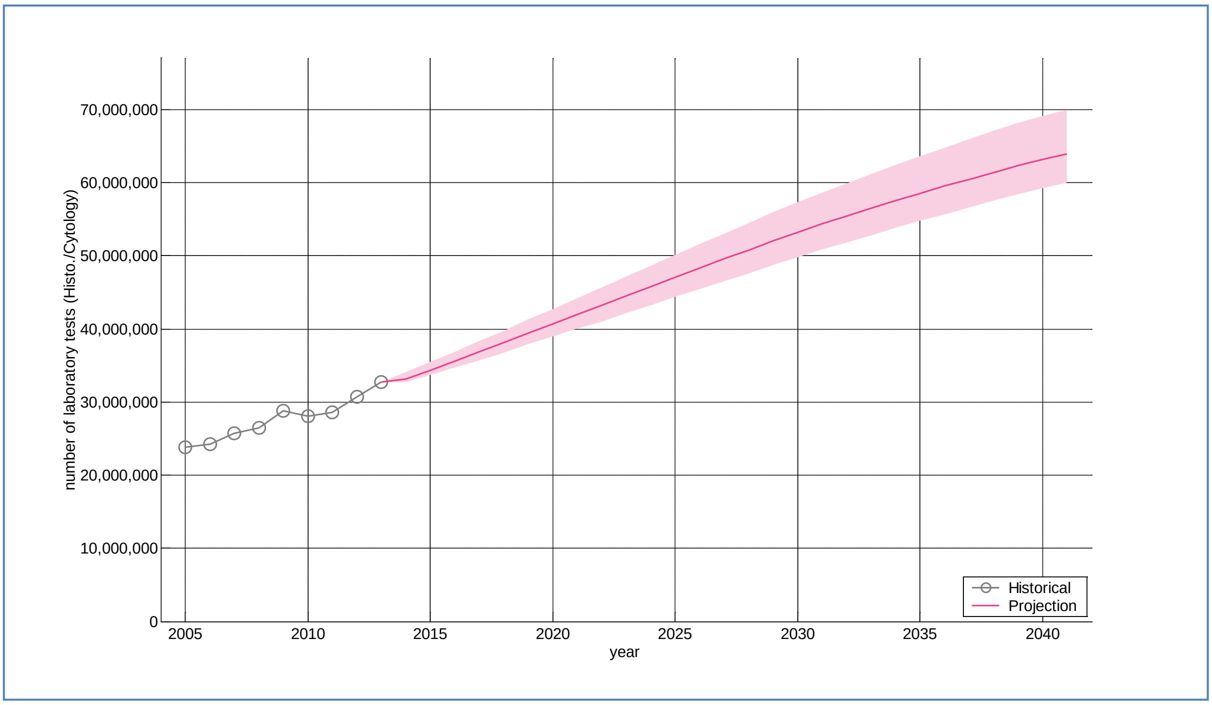

Figure 4.12 Historical and projected number of laboratory tests: Histopathology / Cytology

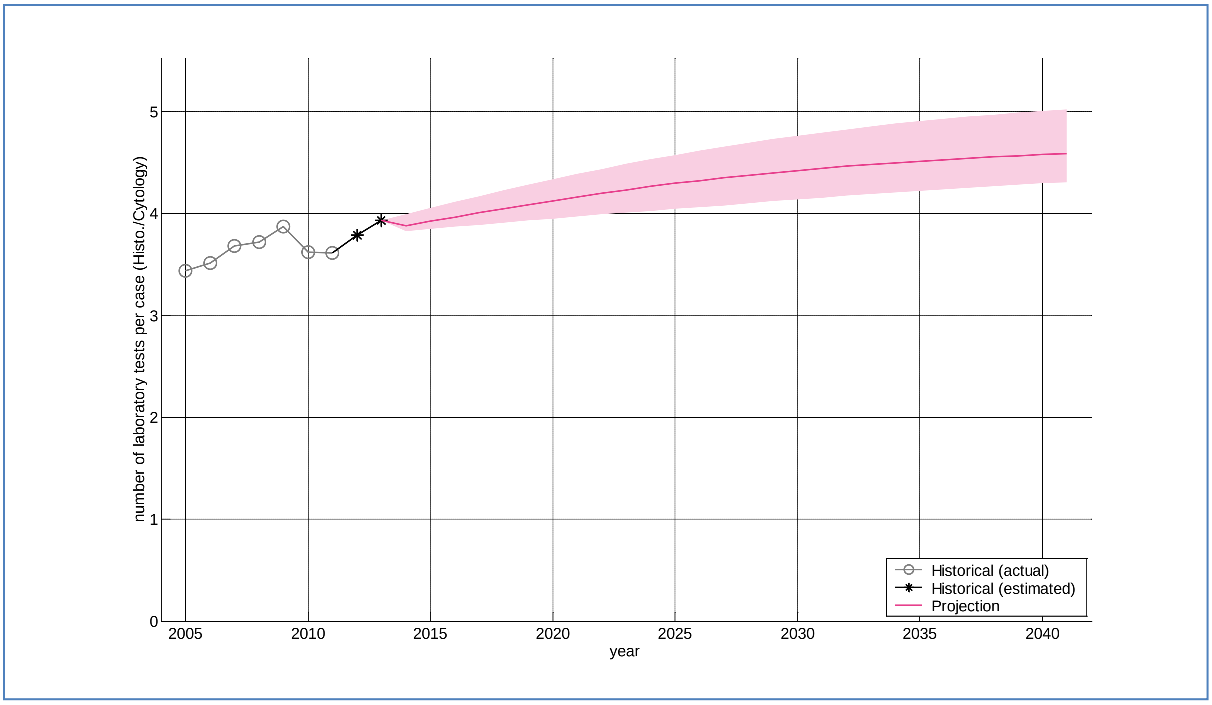

Figure 4.13 Historical and projected number of HA laboratory tests per case: Histopathology / Cytology

Chemical pathology

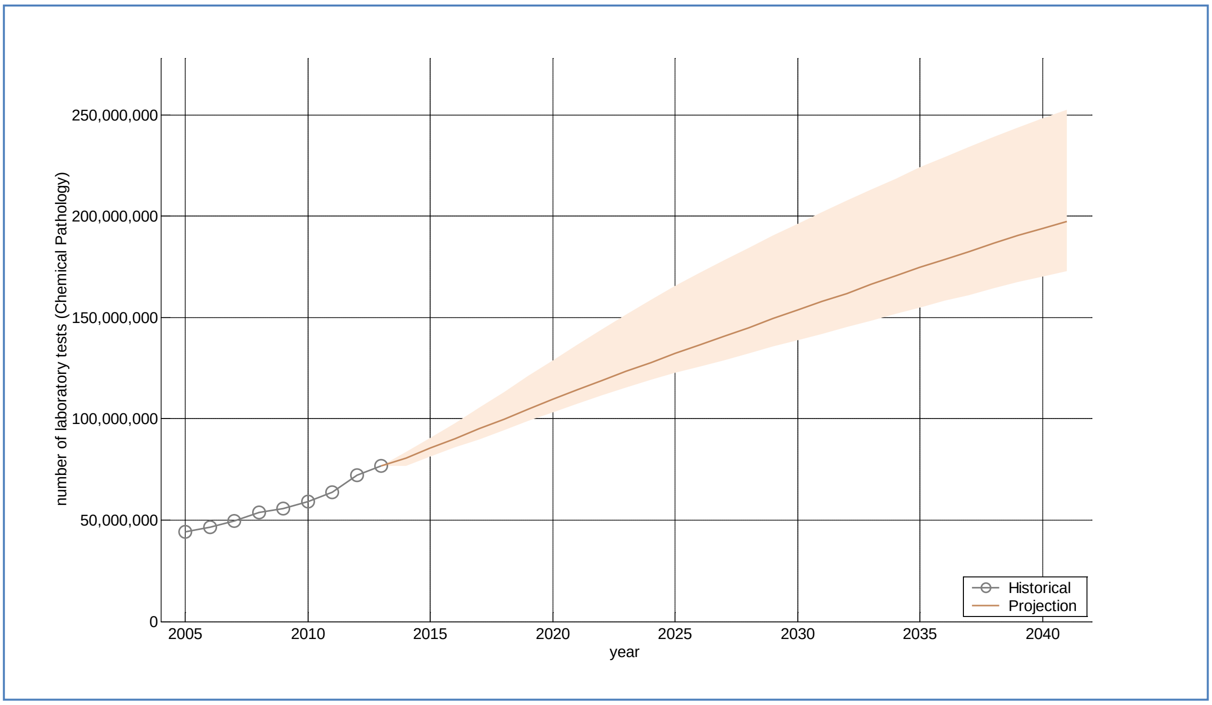

Figure 4.14 Historical and projected number of laboratory tests: Chemical pathology

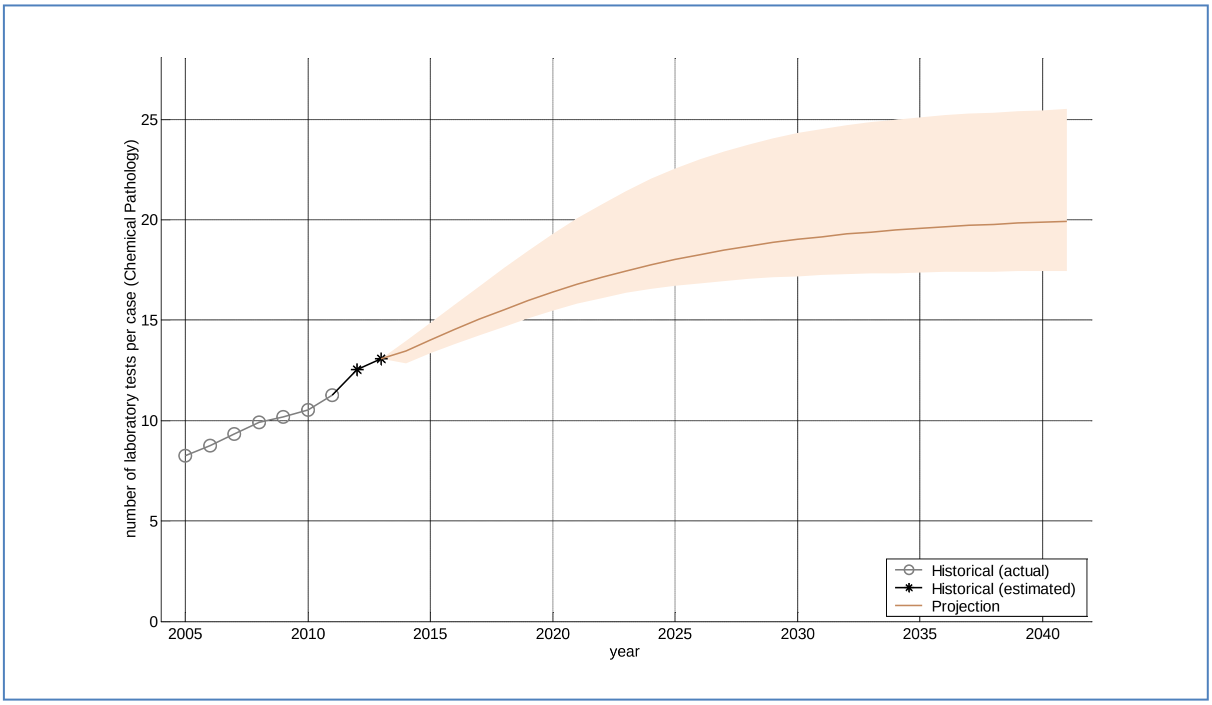

Figure 4.15 Historical and projected number of HA laboratory tests per case: Chemical pathology

Immunology

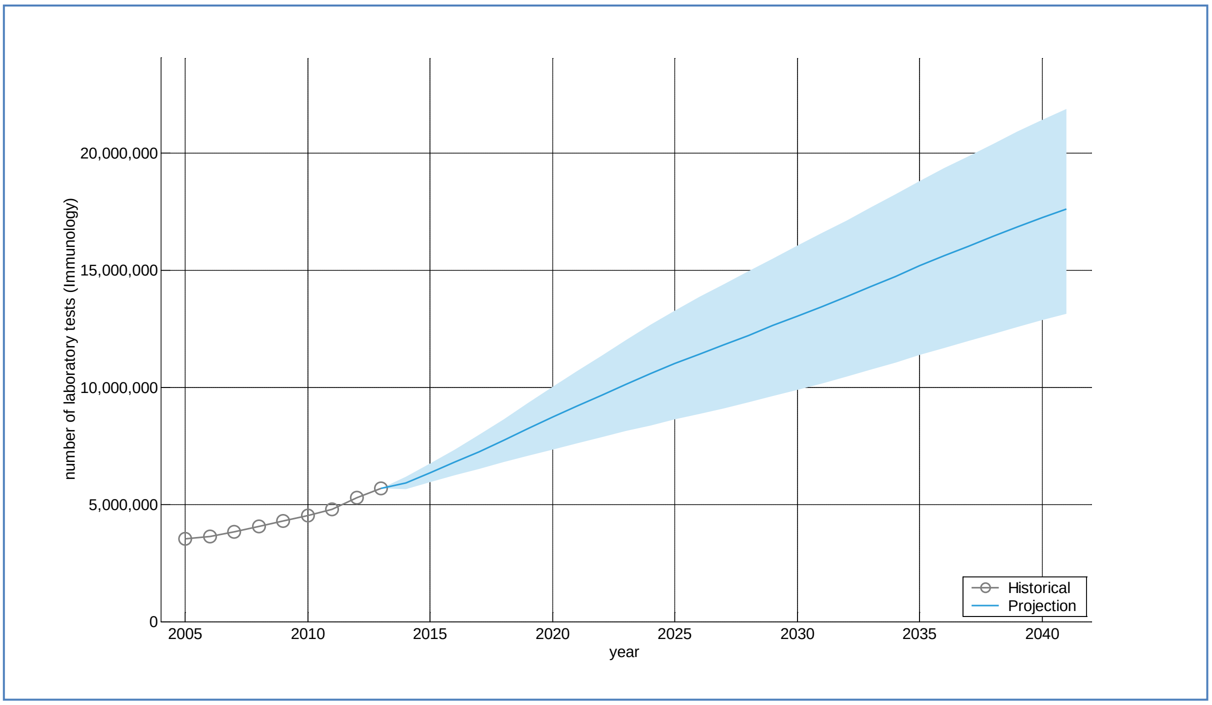

Figure 4.16 Historical and projected number of laboratory tests: Immunology

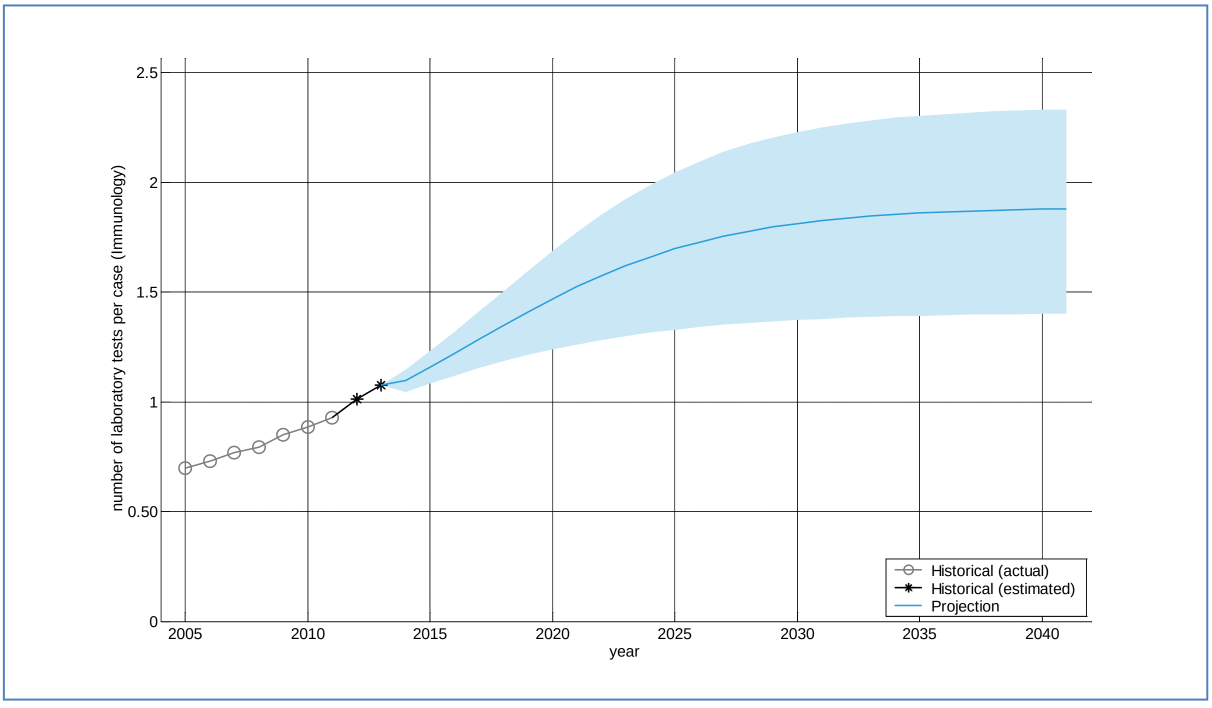

Figure 4.17 Historical and projected number of laboratory tests per case: Immunology

Other pathology

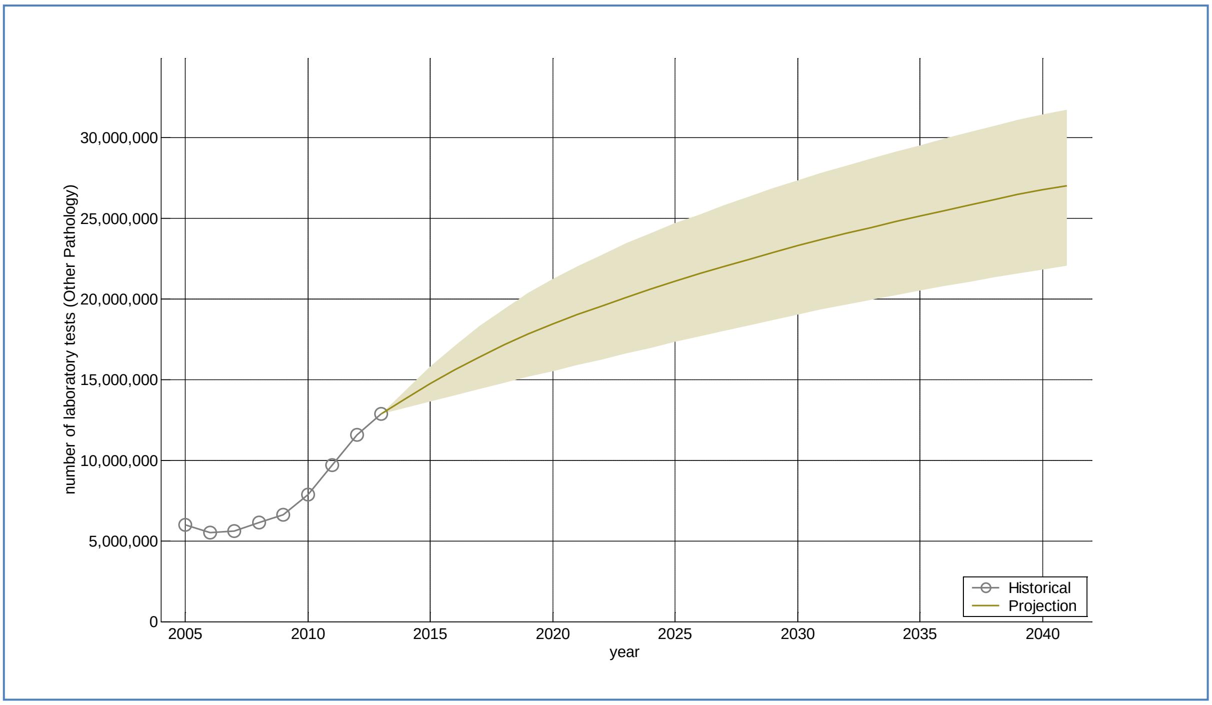

Figure 4.18 Historical and projected number of laboratory tests: Other pathology

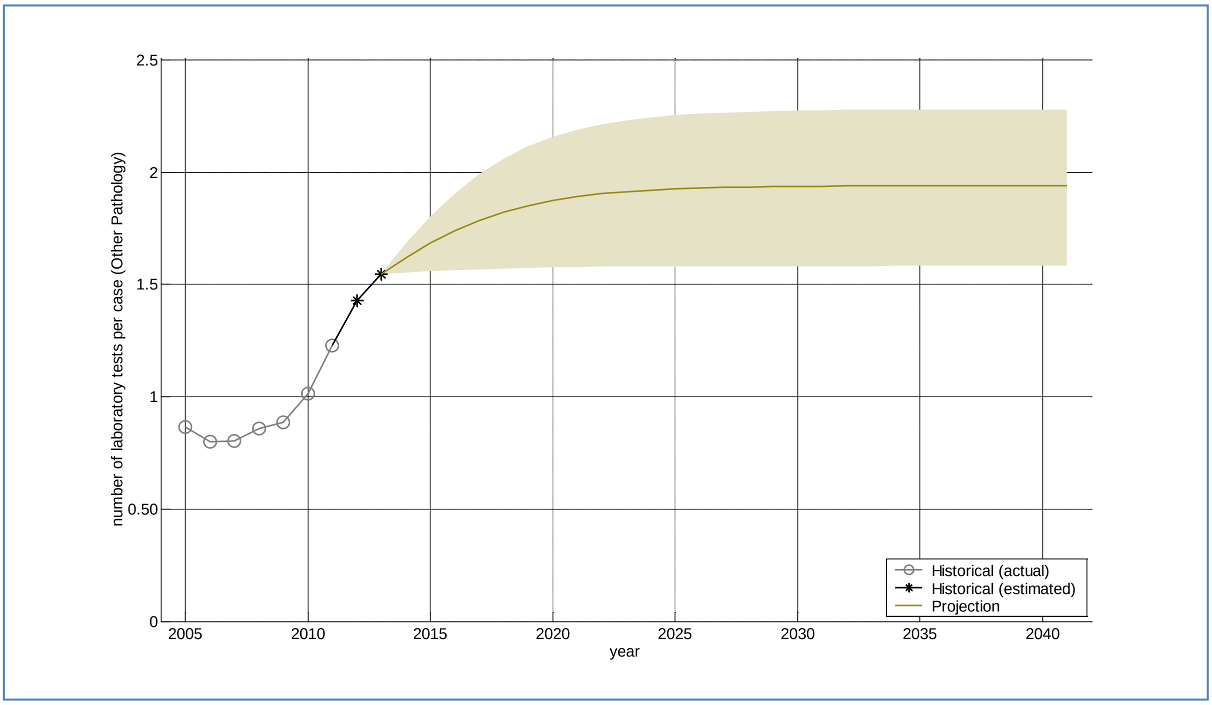

Figure 4.19 Historical and projected number of laboratory tests per case: Other pathology

4.2.1.2 Department of Health

The three functional divisions of the Public Health Laboratory Service Branch (PHLSB) of the Department of Health (DH) (Figure 4.20) provide seven types of laboratory tests.

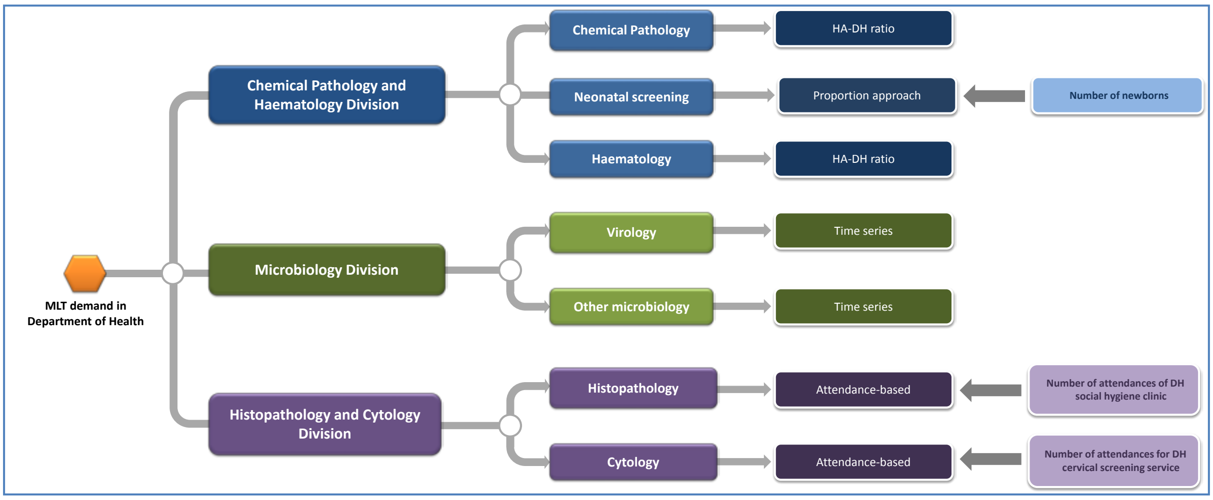

Figure 4.20 Flow diagram of medical laboratory technologist utilisation in the DH PHLSB functional divisions

Haematology tests

The number of DH haematology tests T_{DH}^{1} performed is expressed as a linear proportion of number of haematology tests in HA:-

$$T_{DH}^{1} = T_{HA}^{1} \times \beta_{DH}^{1}$$

where T_{HA}^{1} number of haematology tests in HA

β_{DH}^{1} HA-DH haematology test proportion.

A three-fold increase in the number of DH haematology tests is projected (Figure 4.22).

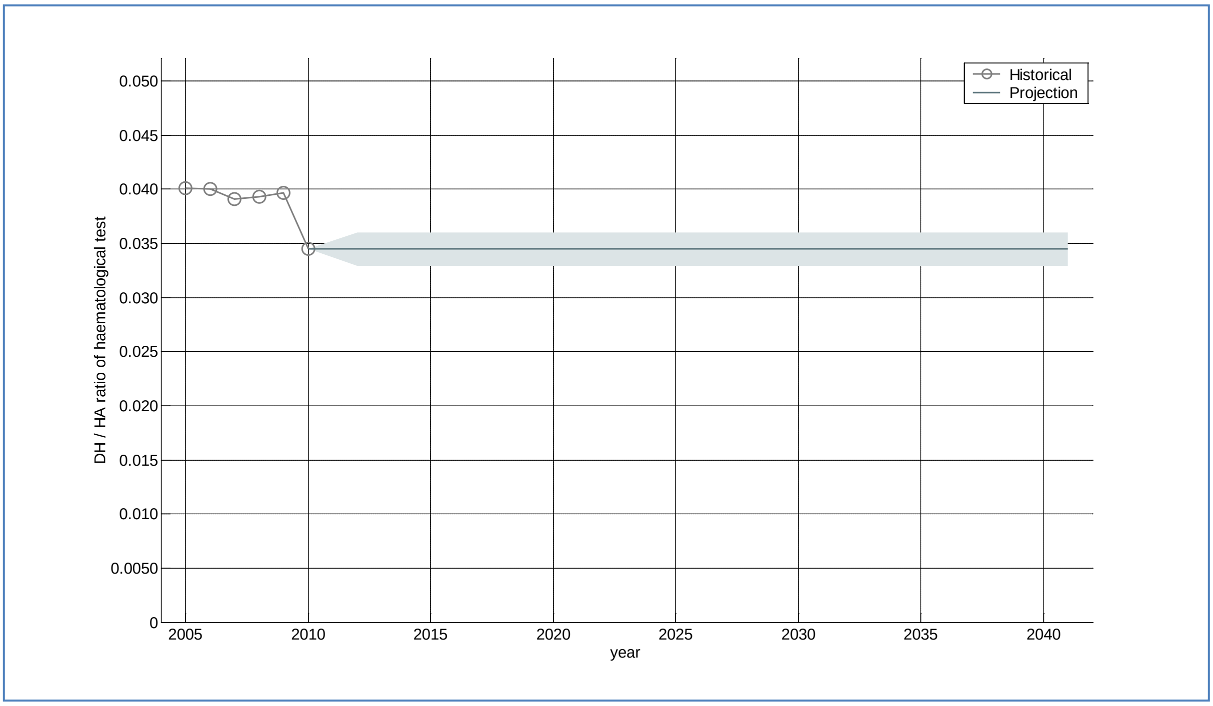

Figure 4.21 Historical and projected DH / HA haematology test ratio

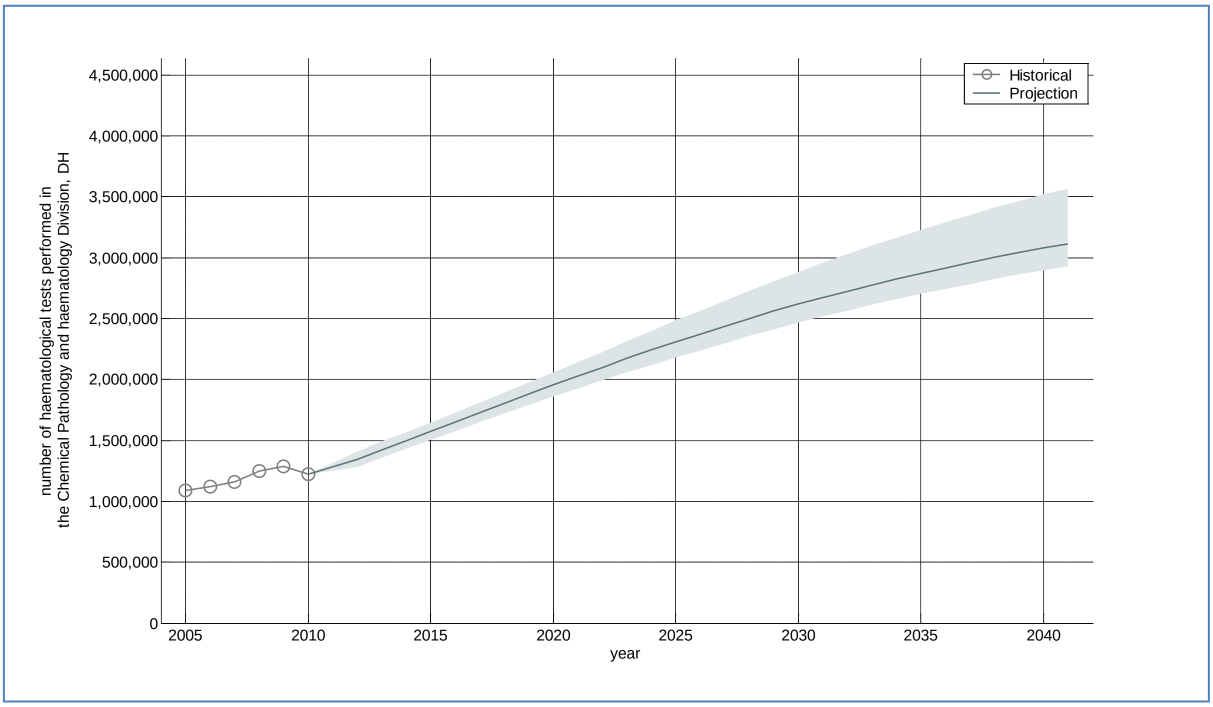

Figure 4.22 Historical and projected number of haematology tests

Chemical Pathology tests

The number of DH chemical pathology tests T_{DH}^{2} is expressed as a linear proportion of number of HA chemical pathology tests as follows:-

$$T_{DH}^{2} = T_{HA}^{5} \times \beta_{DH}^{2}$$

where T_{HA}^{5} number of HA chemical pathology tests in Hospital Authority

β_{DH}^{2} HA-DH chemical pathology test proportion.

A three-fold increase in the number of DH chemical pathology tests is projected (Figure 4.24).

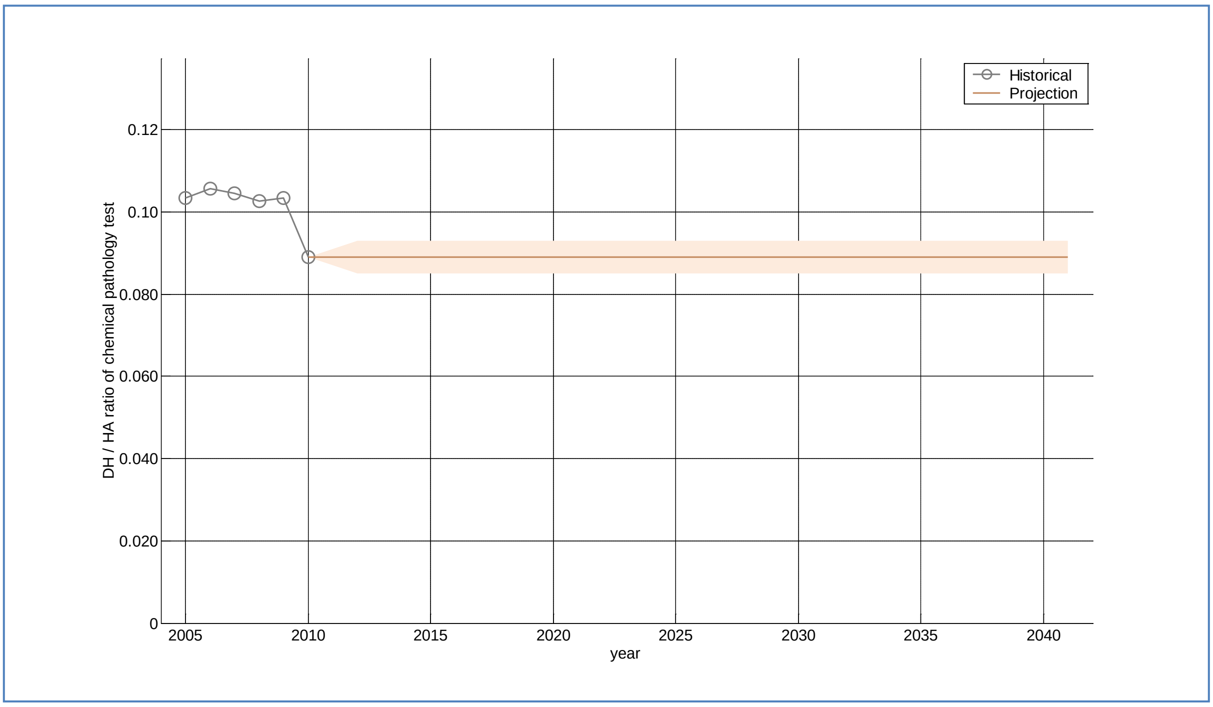

Figure 4.23 Historical and projected DH / HA chemical pathology test ratio

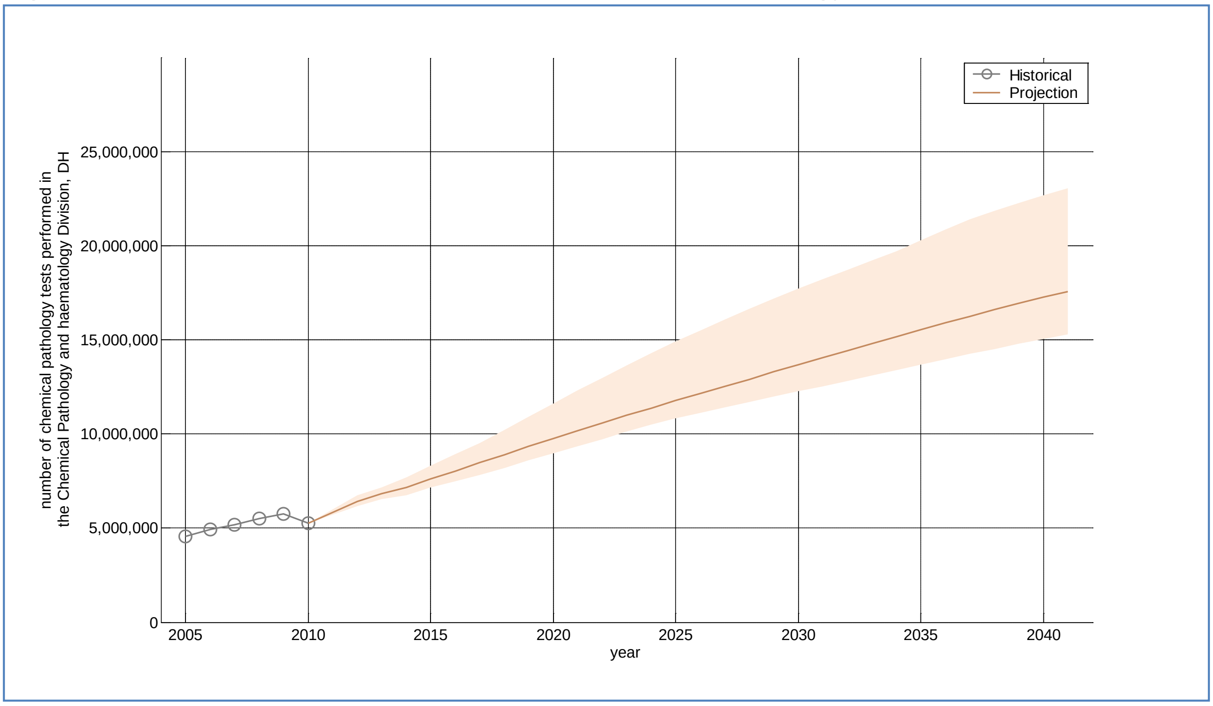

Figure 4.24 Historical and projected number of DH chemical pathology tests

Microbiology tests

The microbiology tests conducted by PHLSB include clinical microbiology, mycobacteriology, food and water, syphilis serology, malaria and virology. As the trend in the number of virology tests differs from the other microbiology tests, the microbiology projection is decomposed into two sub-categories: virology and other tests and projected by different methods:

$$Number\ of\ microbiology\ tests\ (T_{DH}^{6}) \\ = Number\ of\ virology\ tests\ (v_{DH}^{6}) \\ + Number\ of\ other\ microbiology\ tests\ (o_{DH}^{6})$$

Virology tests

Microbiology is such a broad category of laboratory tests that having DH's virology tests being expressed as a linear proportion of the number of HA microbiology tests is not valid and appropriate. Therefore, a time series analysis is adopted in this section. The number of virology tests is projected to sharply increase throughout the projection period (Figure 4.26).

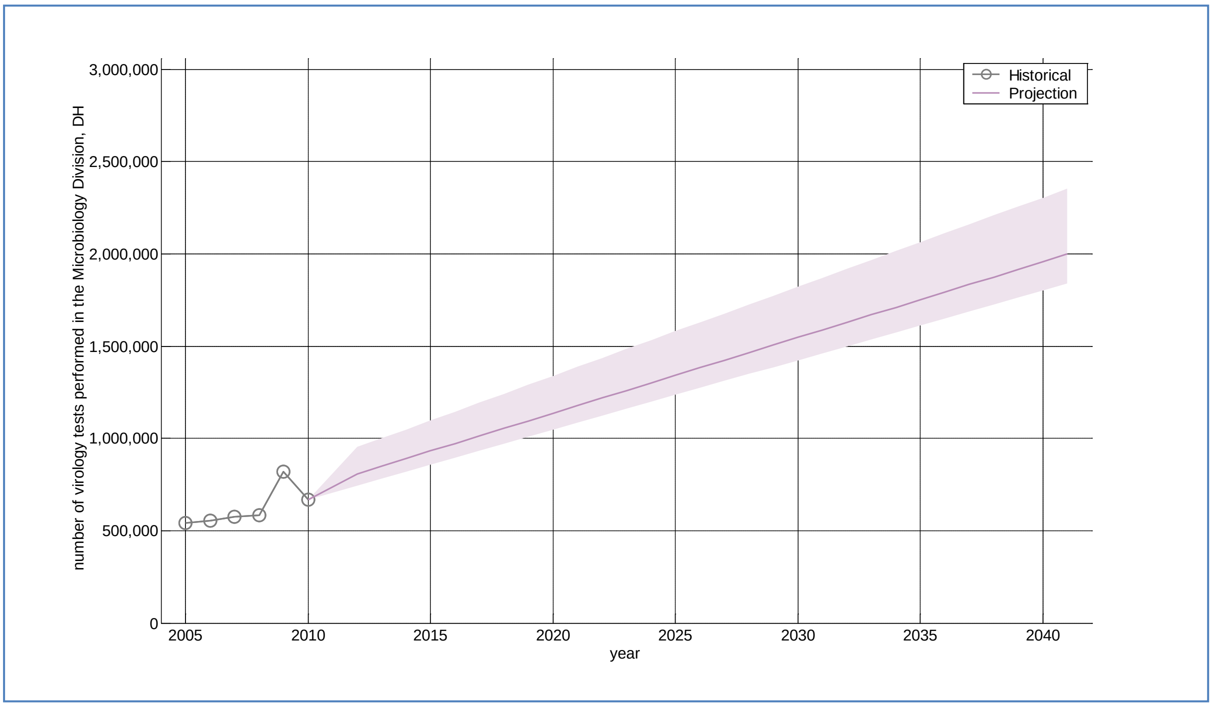

Figure 4.25 Historical and projected number of DH virology tests

Other microbiology test

The number of mycobacteriology, bacteriology and parasitology, mycology, microbial serology, malaria, epidemiology and molecular, food and water, and vaccine and biological product tests are projected using time series analysis (Figure 4.27).

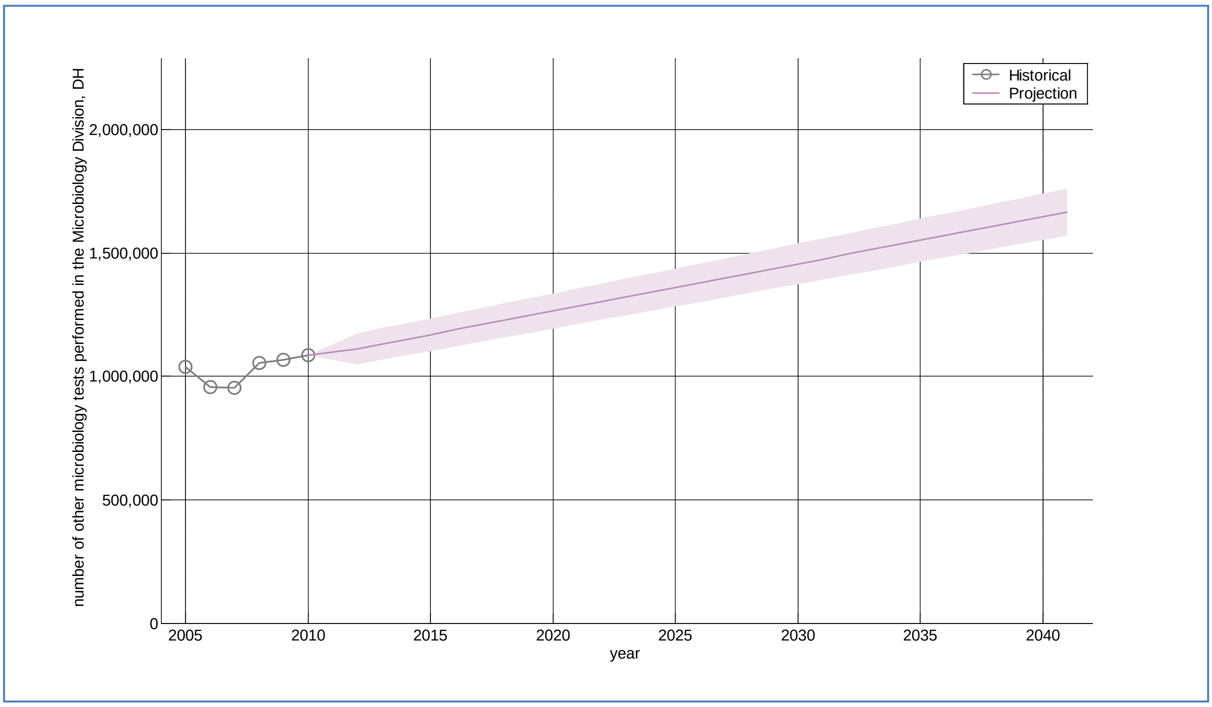

Figure 4.26 Historical and projected number of DH other microbiology tests

Histopathology tests

The number of histopathology tests is expressed as a linear proportion to the number of DH social hygiene clinic attendances:

$$T_{DH}^{4} = A_{SH} \times \beta_{DH}^{4}$$

where A_{SH} number of attendances for DH social hygiene clinic

β_{DH}^{4} number of histopathology tests per DH social hygiene clinic attendance.

The number of DH social hygiene clinic visits at year *y*, $A_{SH}(y)$ is further expressed as:-

$$A_{SH}(y) = \sum_{a,s} r_{SH}(a,s,y) \times H(a,s,y)$$

where $r_{SH}(a,s,y)$ DH social hygiene clinic attendance rate by age-, sex- group (*a*,*s*) at year *y*,

$H(a,s,y)$ population size by age-, sex- group (a,s) at year y.

As the age-, sex- specific attendance volume (and hence attendance rate) is available only for 2011 and the 2005 and 2010 attendance volume is aggregated, the age-, sex volume is approximated as $r_{SH}(a,s,2011)$ for all a and s:-

$$A_{SH}(y) \approx \tilde{A}_{SH}(y) = \sum_{a,s} r_{SH}(a,s,2011) \times H(a,s,y)$$

Although, the DH social hygiene attendance rate increases with age (Figure 4.28) the number of social hygiene attendances are projected to be stable across the period (Figure 4.29) as are the histopathology tests per attendance (Figure 4.30). The number of histopathology tests although declining throughout the historical period is projected to flatten and slightly increase (Figure 4.31)

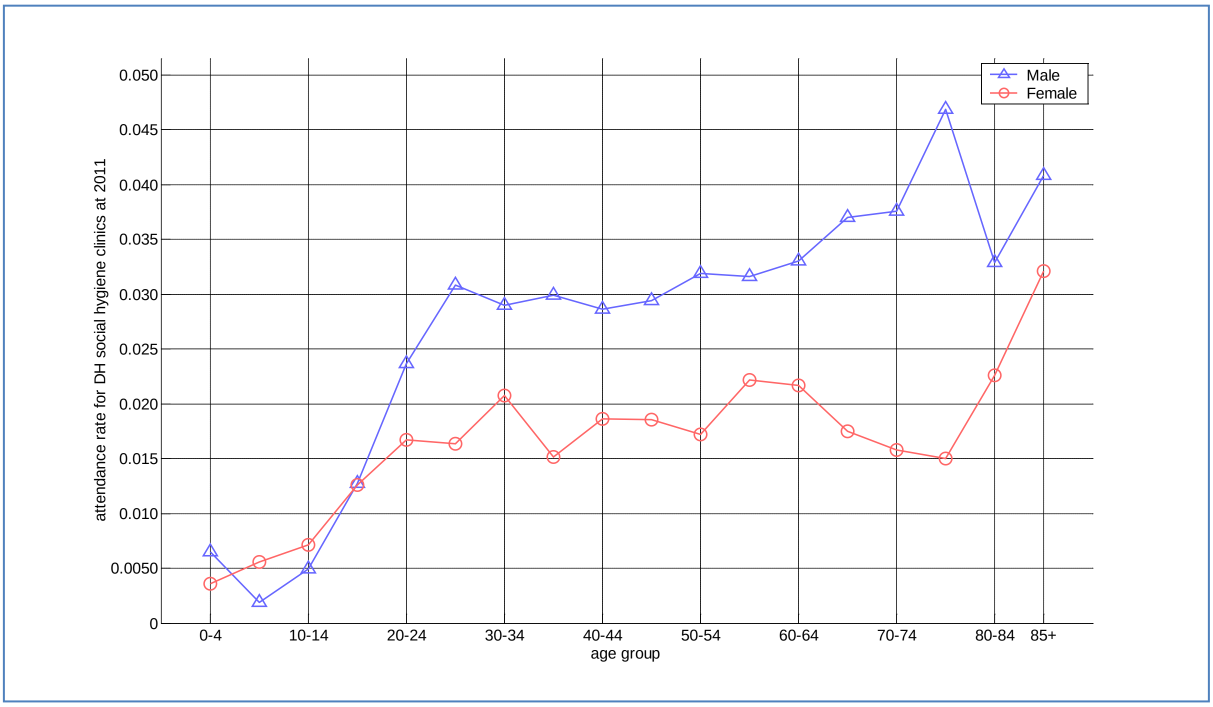

Figure 4.27 DH social hygiene clinics in 2011 - age group specific attendance rate by sex.

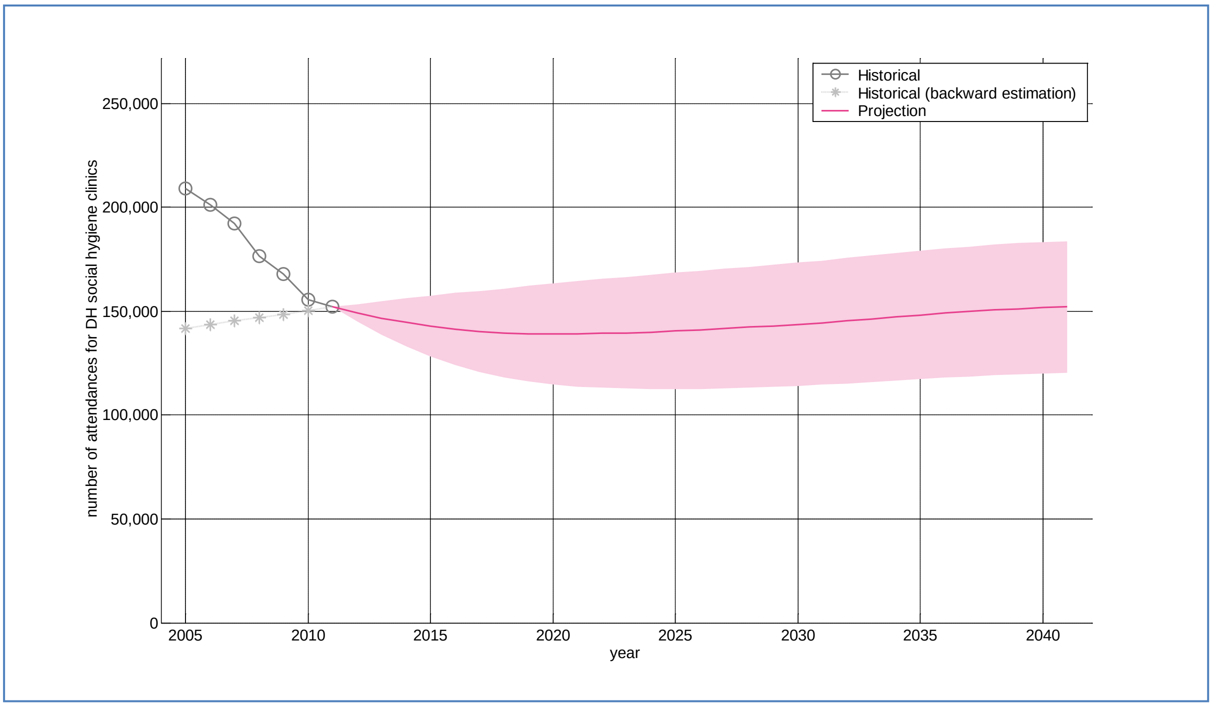

Figure 4.28 Historical and projected number of DH social hygiene clinics attendances

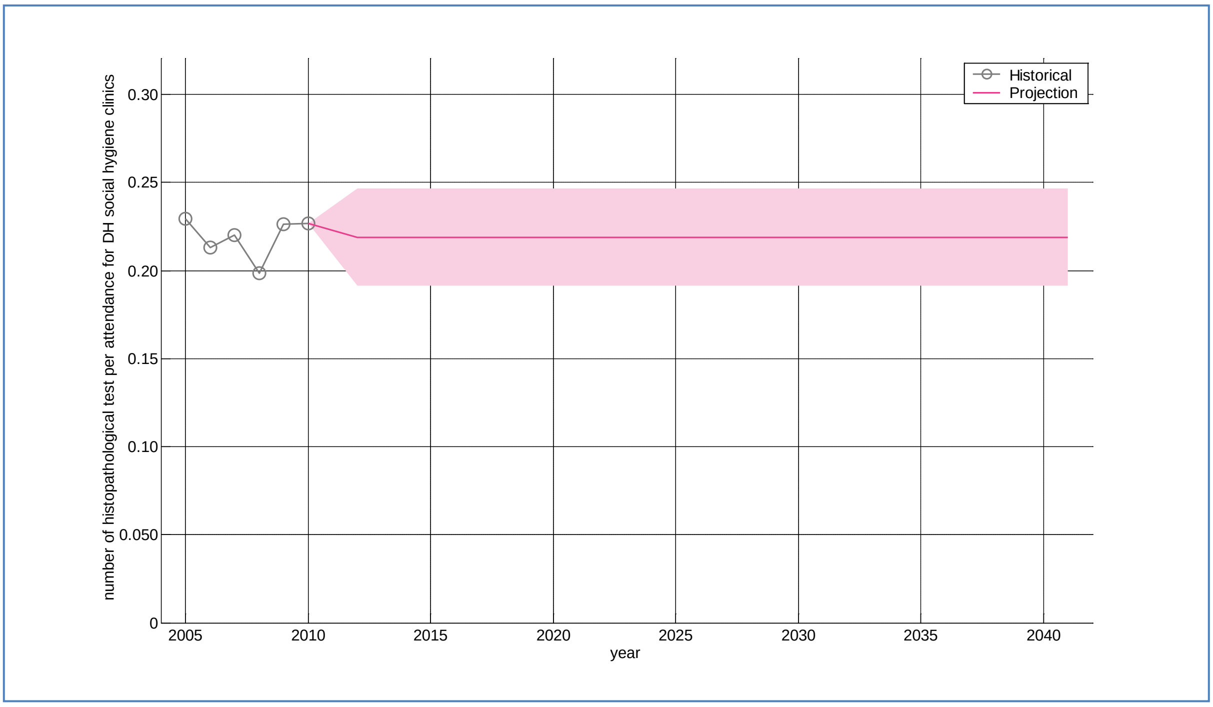

Figure 4.29 Historical and projected number of DH histopathology tests per social hygiene clinic attendance

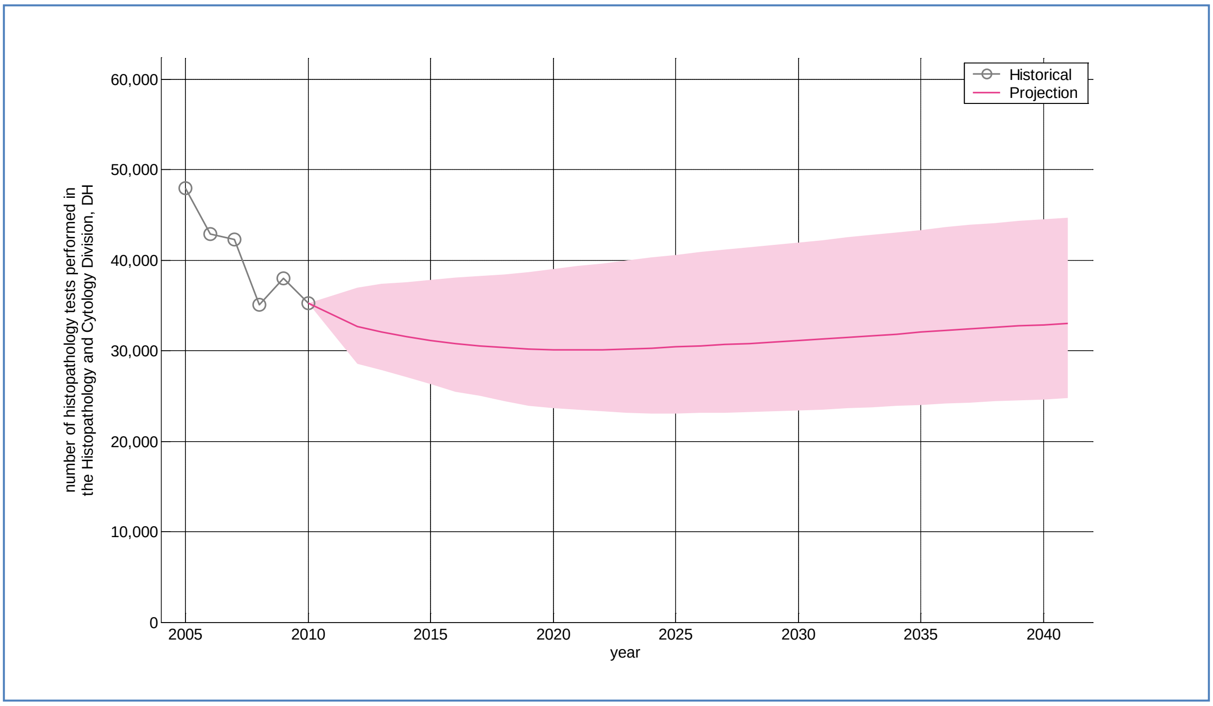

Figure 4.30 Historical and projected number of DH histopathology tests

Cytology tests

The number of cytological tests is expressed as a linear proportion to the number of DH cervical screening service attendances:

$$T_{DH}^{5} = A_{CV} \times \beta_{DH}^{5}$$

where A_{CV} number of DH cervical screening service attendances

β_{DH}^{5} number of cytology tests per DH cervical screening service attendance.

The number of DH cervical screening service attendances at year y, $A_{CV}(y)$ is further expressed as:-

$$A_{CV}(y) = \sum_{a,s} r_{CV}(a,s,y) \times H(a,s,y)$$

where $r_{CV}(a,s,y)$ DH cervical screening service attendance age-, sex group (a,s) rate at year y,

$H(a,s,y)$ population size age-, sex group (a,s) at year y.

The number of cytology tests per cervical screening service attendance is projected to slowly increase (Figure 4.34).

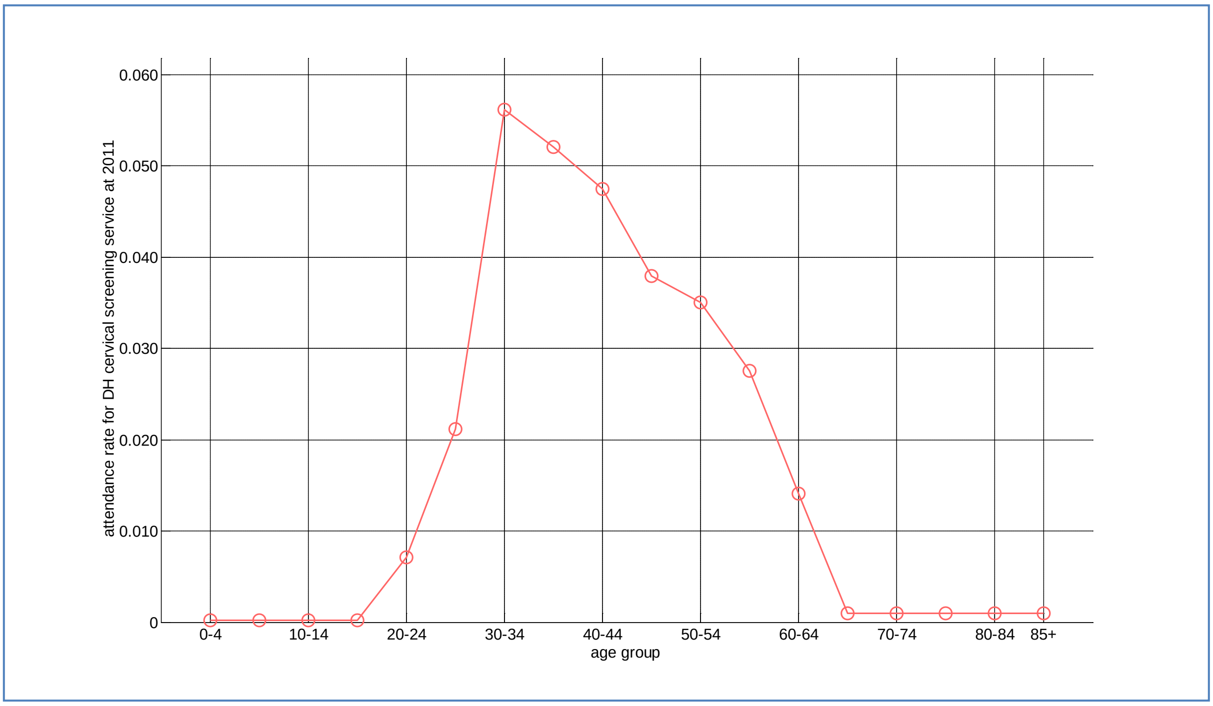

Figure 4.31 DH cervical screening service attendance rate by age- group (2011)

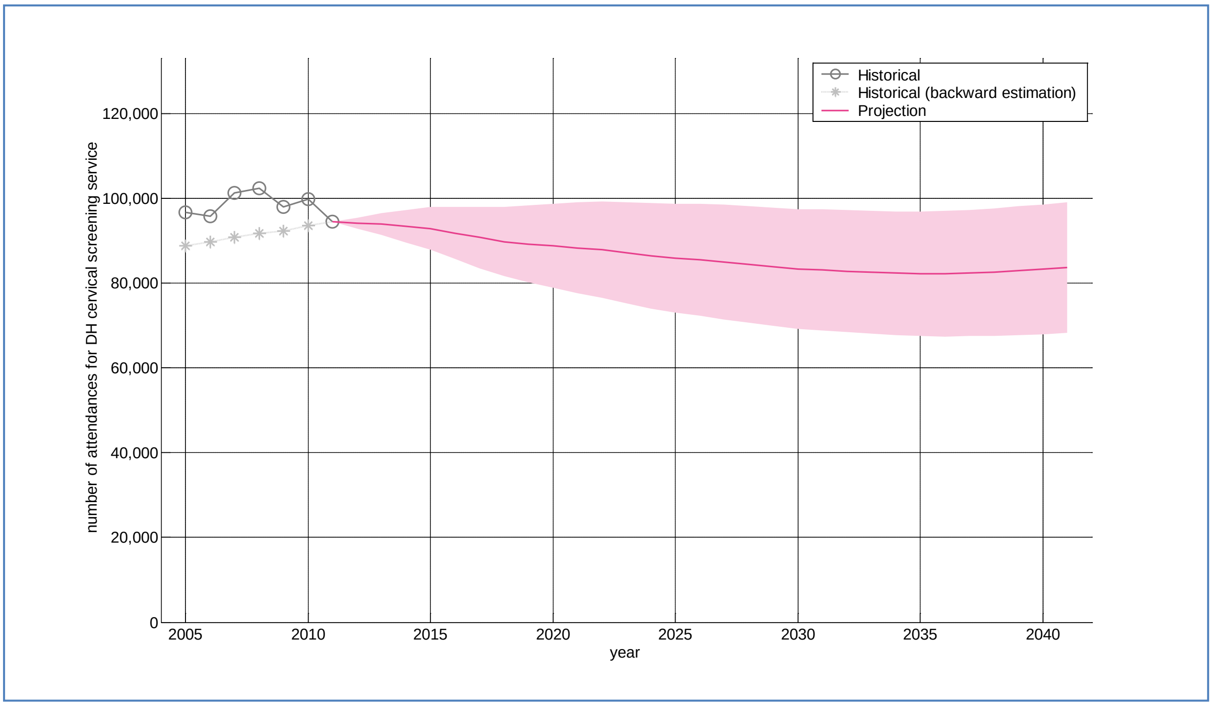

Figure 4.32 Historical and projected number of DH cervical screening service attendances

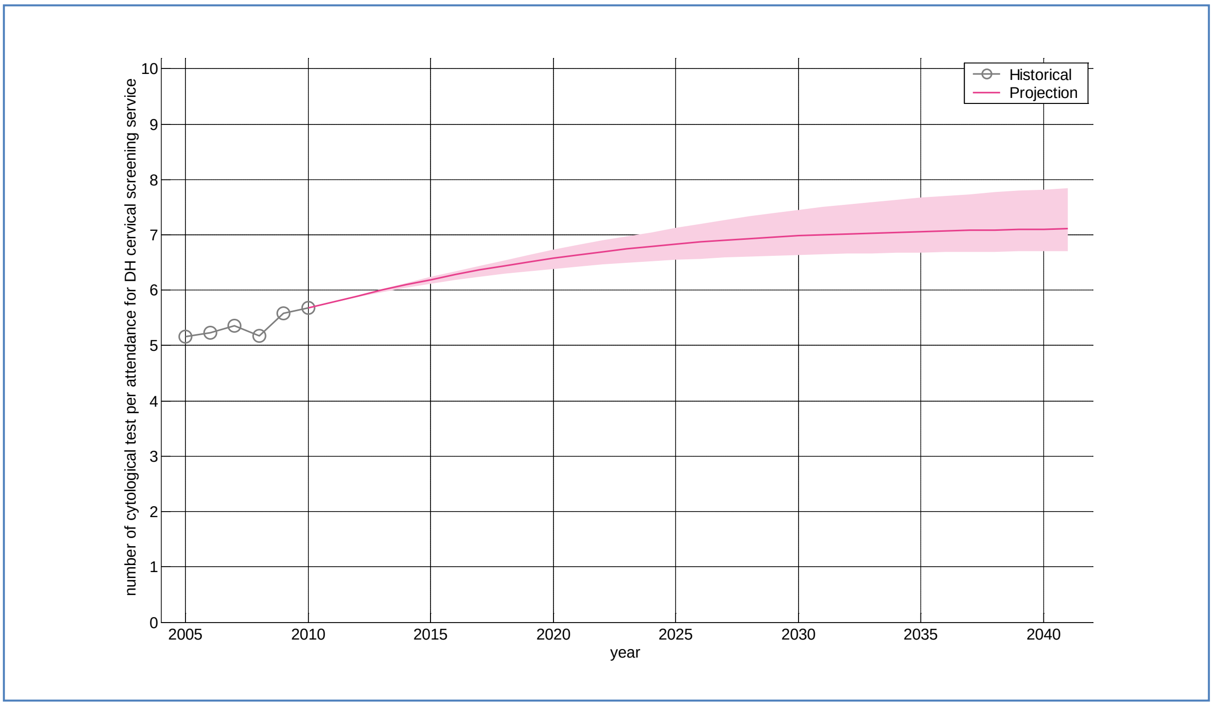

Figure 4.33 Historical and projected number of cytological tests per DH cervical screening service attendance

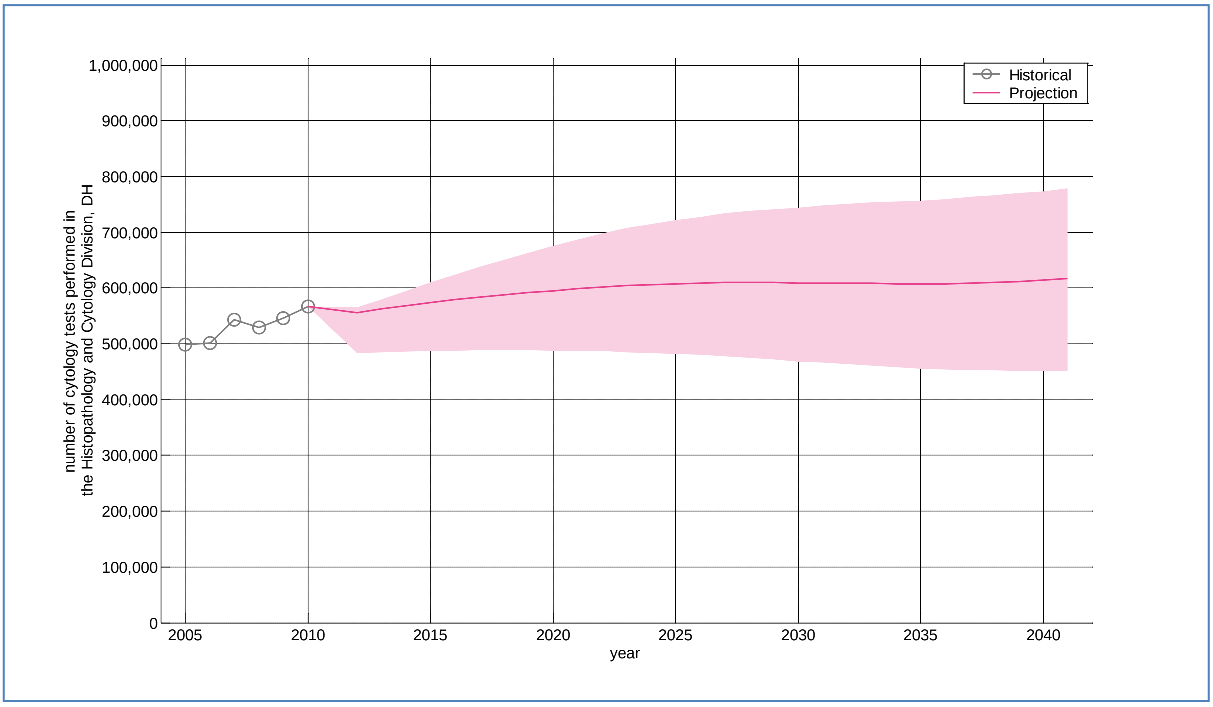

Figure 4.34 Historical and projected number of cytological tests performed in the DH

Neonatal Screening test

The number of neonatal screening tests T_{DH}^{5} is expressed as a linear proportion of number of newborns in Hong Kong:-

$$T_{DH}^{5} = B \times \beta_{DH}^{5}$$

where B number of newborns in Hong Kong

β_{DH}^{5} number of clinical immunology tests per newborn.

The number of neonatal screening tests are projected to sharply increase between 2010 and 2012 and then slowly decline (Figure 4.37).

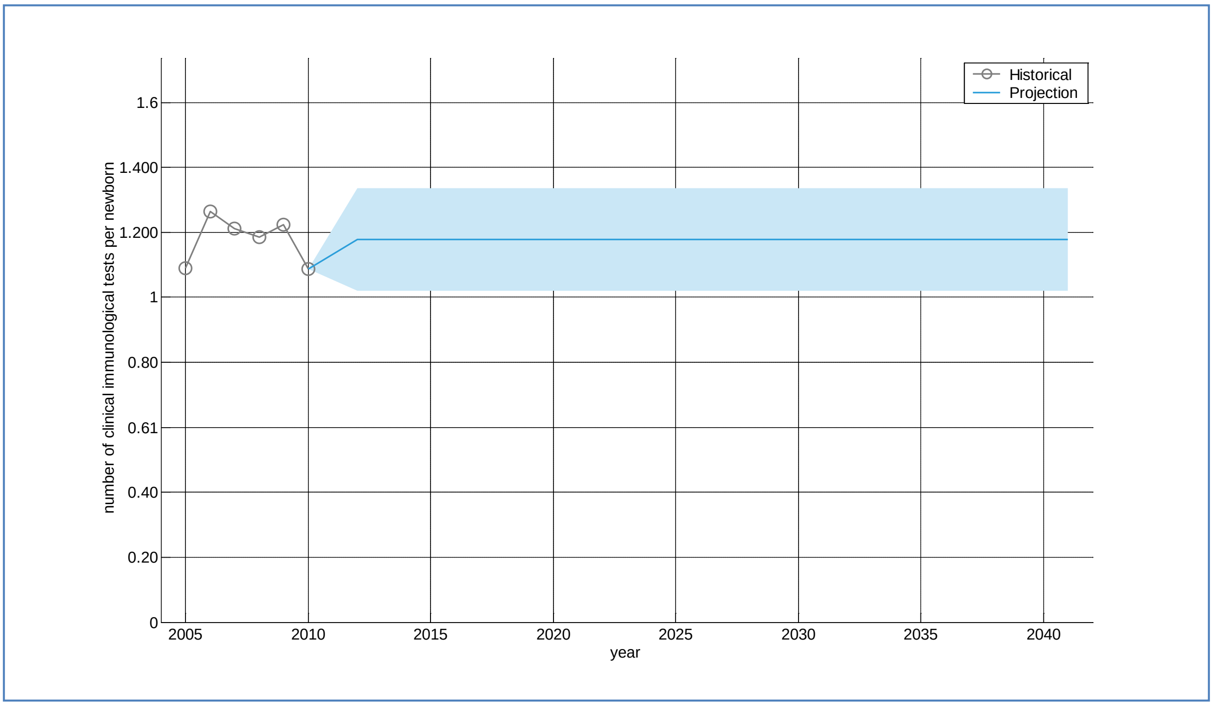

Figure 4.35 Historical and projected number of neonatal screening tests per newborn

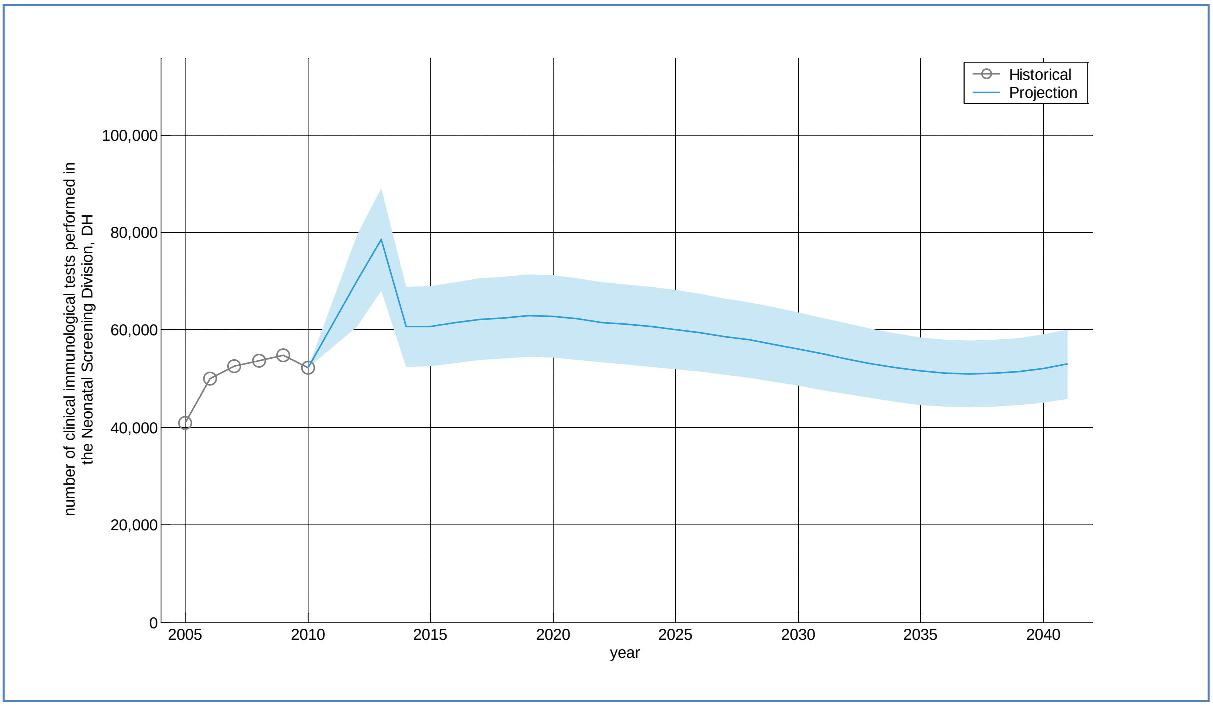

Figure 4.36 Historical and projected number of DH neonatal screening test

4.2.2 Medical laboratory service utilisation - Private sector

4.2.2.1 Private medical clinic/laboratory

'Private medical clinic' refers to Medical clinics registered under Section 5 of the Medical Clinic Ordinance (Chapter 343). Demand for MLTs in private medical clinics, medical & X-ray laboratory at year y, $F_{private}(y)$, is expressed as:-

$$F_{private}(y) = w(y)Q(y)$$

where w is the number of MLT FTEs per for private laboratory test

Q is the number of private laboratory tests.

To determine the impact of age on the number of private laboratory tests, Q is further expressed as:-

$$Q(y) = \sum_{a,s} r_Q(a,s,y)H(a,s,y)$$

where $r_Q(a,s,y)$ private laboratory test age-, sex- group (a,s) rate at year y,

$H(a,s,y)$ age-, sex- specific Hong Kong population size at year y

$r_Q(a,s,y) = r_Q(a,s,2008)$ for all y

The number of private sector blood (Figure 4.39), urine (Figure 4.41), stool (Figure 4.43), and Pap smear (Figure 4.45) tests are projected to increase slowly.

Blood test

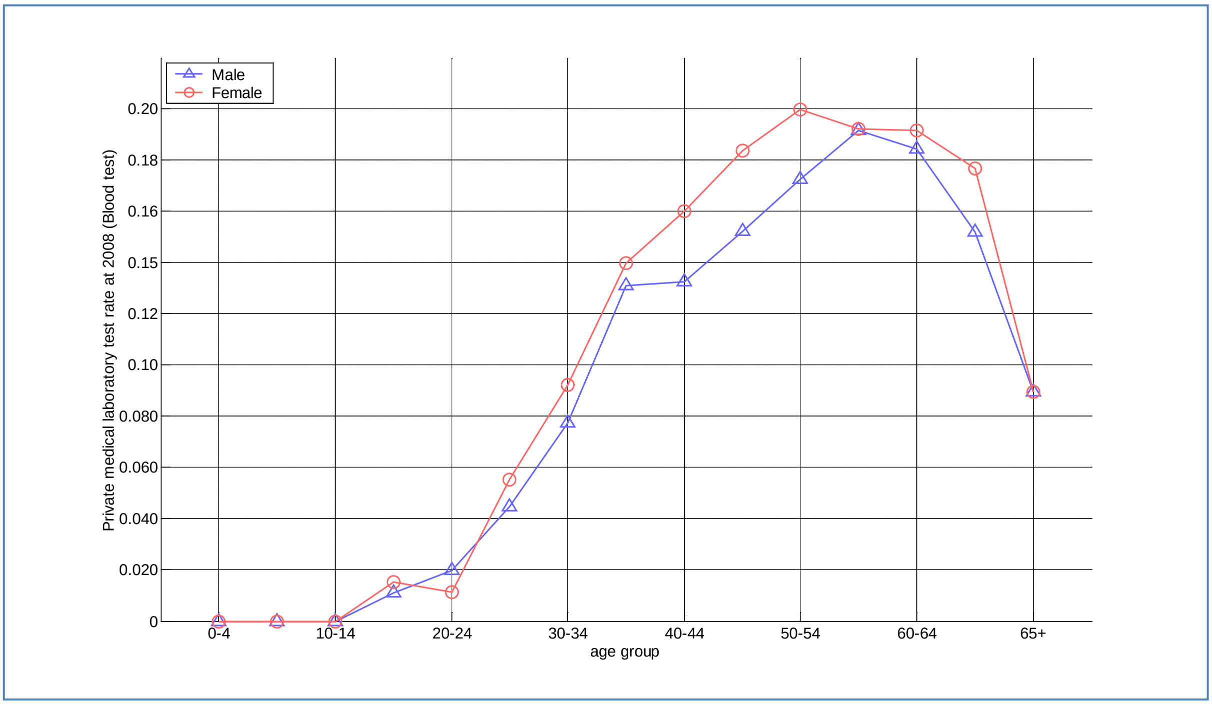

Figure 4.37 Private laboratory age, sex- blood test rate at 2008

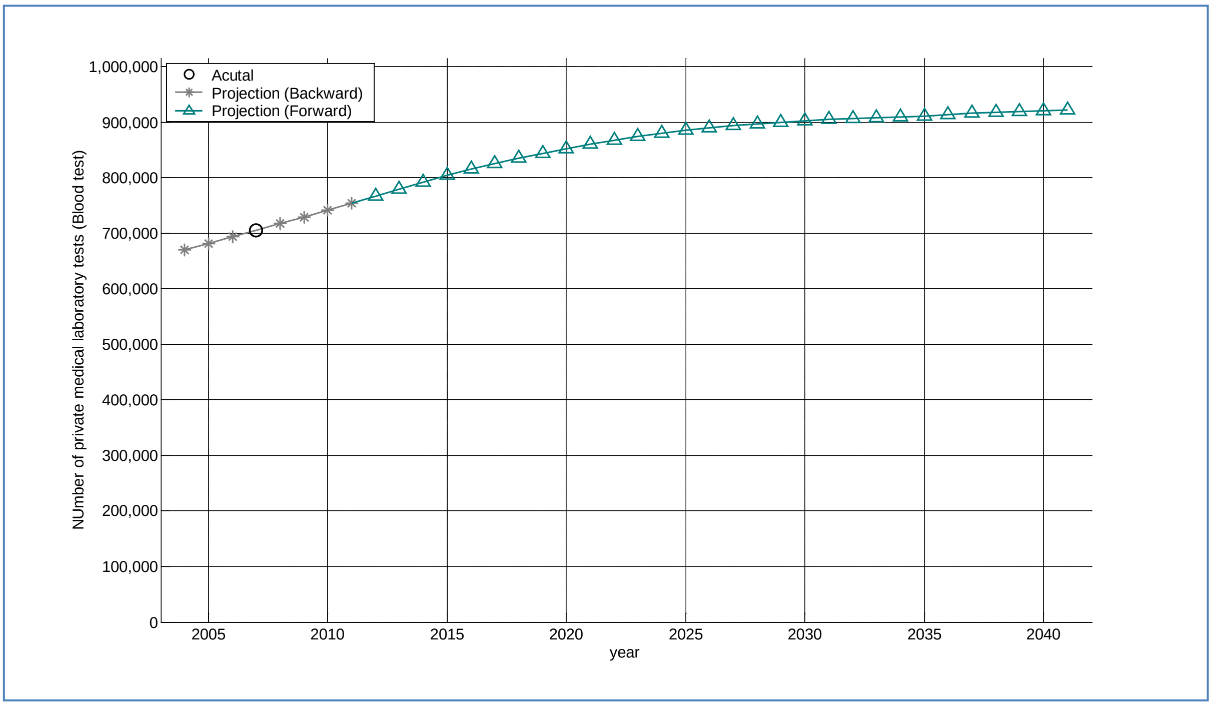

Figure 4.38 Historical and projected number of private laboratory blood tests

Urine test

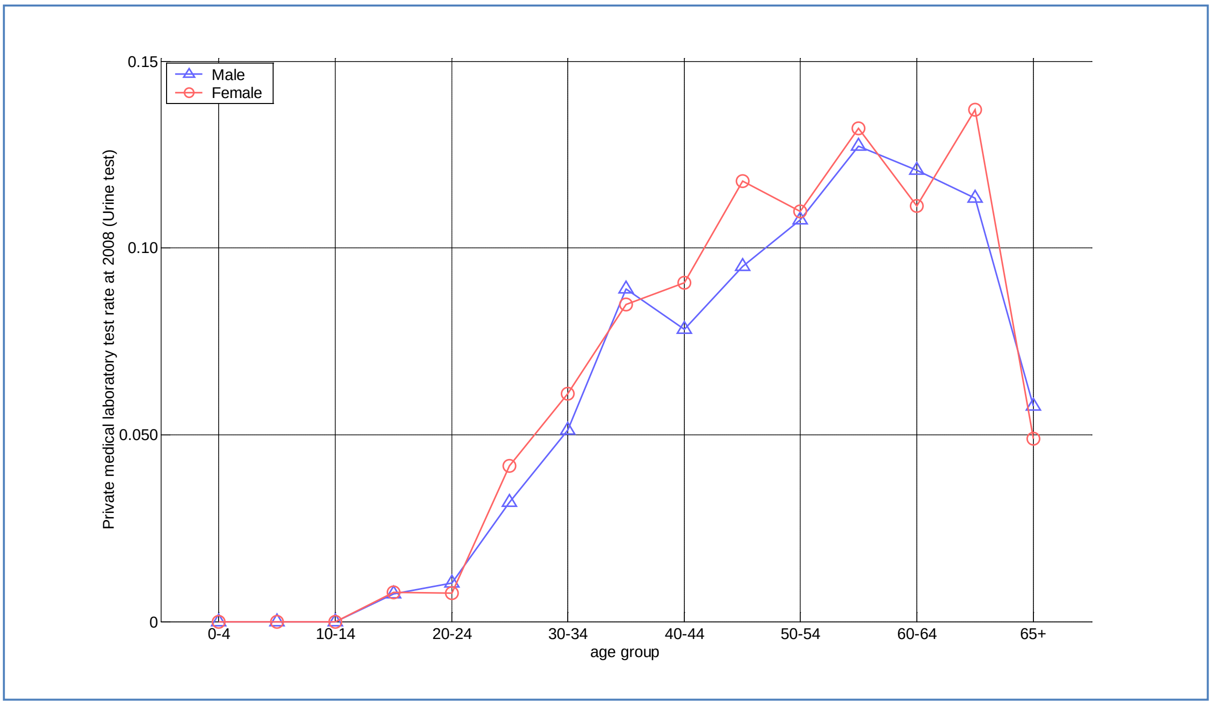

Figure 4.39 Private laboratory age, sex- urine test rate at 2008

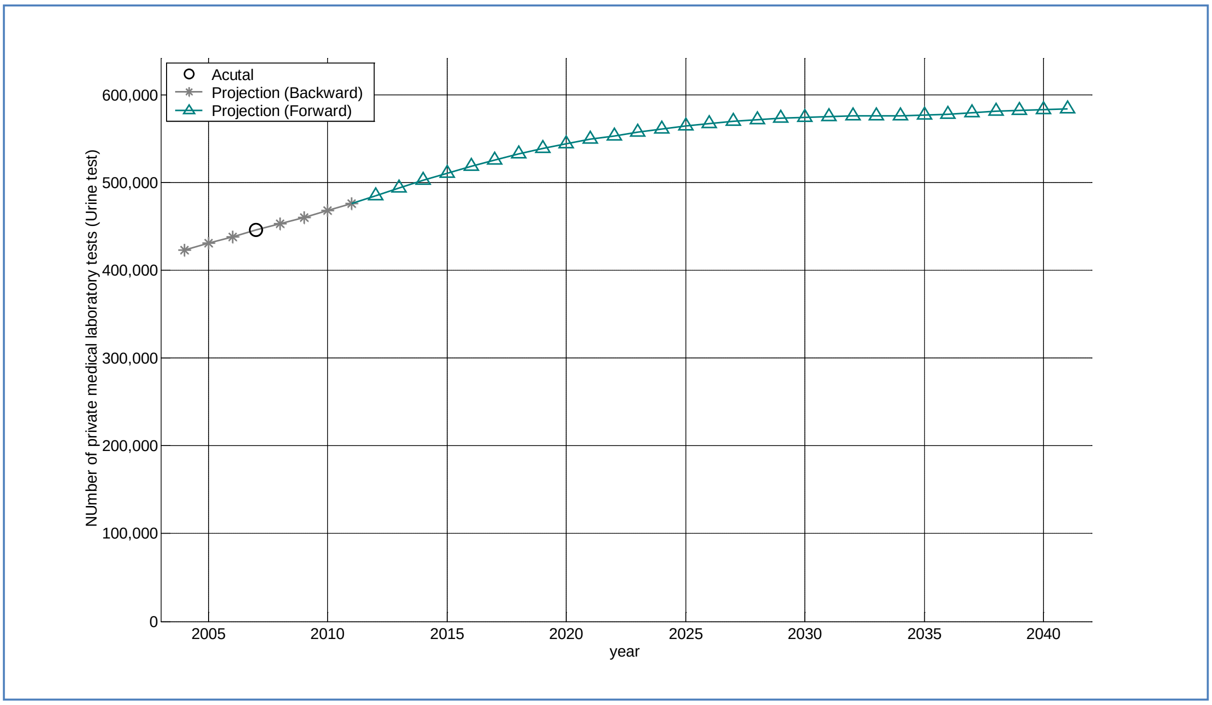

Figure 4.40 Historical and projected number of private laboratory urine tests

Stool test

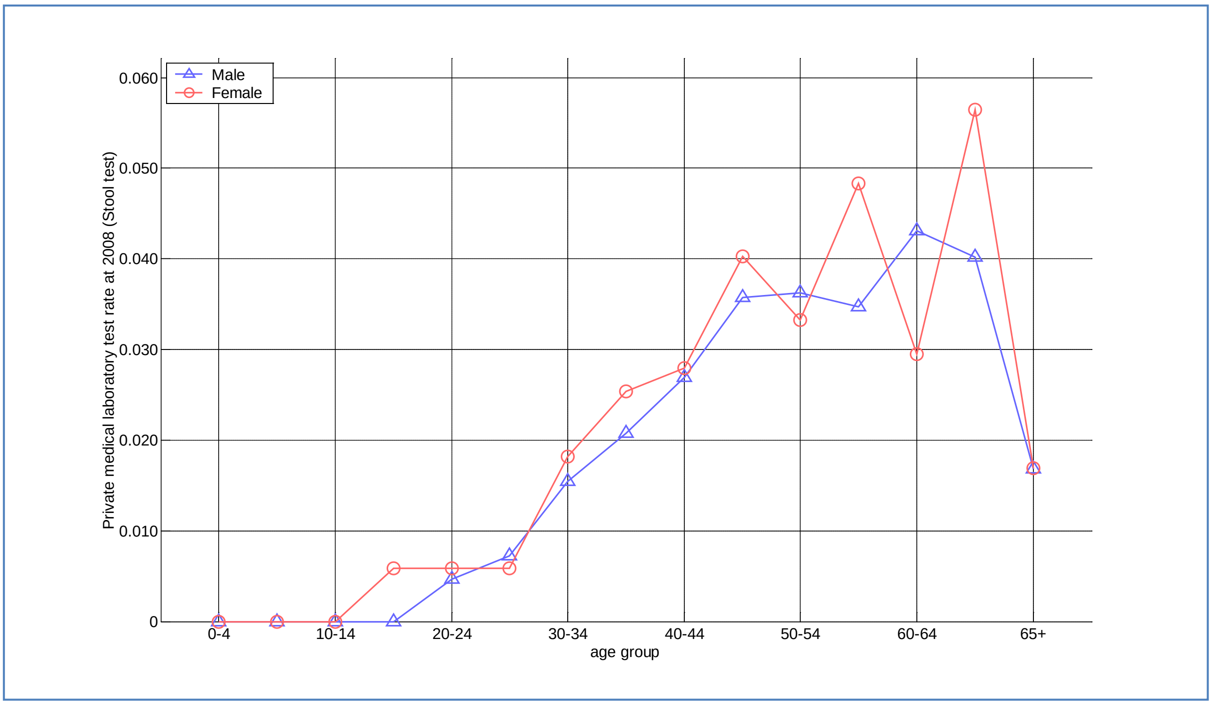

Figure 4.41 Private laboratory age, sex- stool test rate at 2008

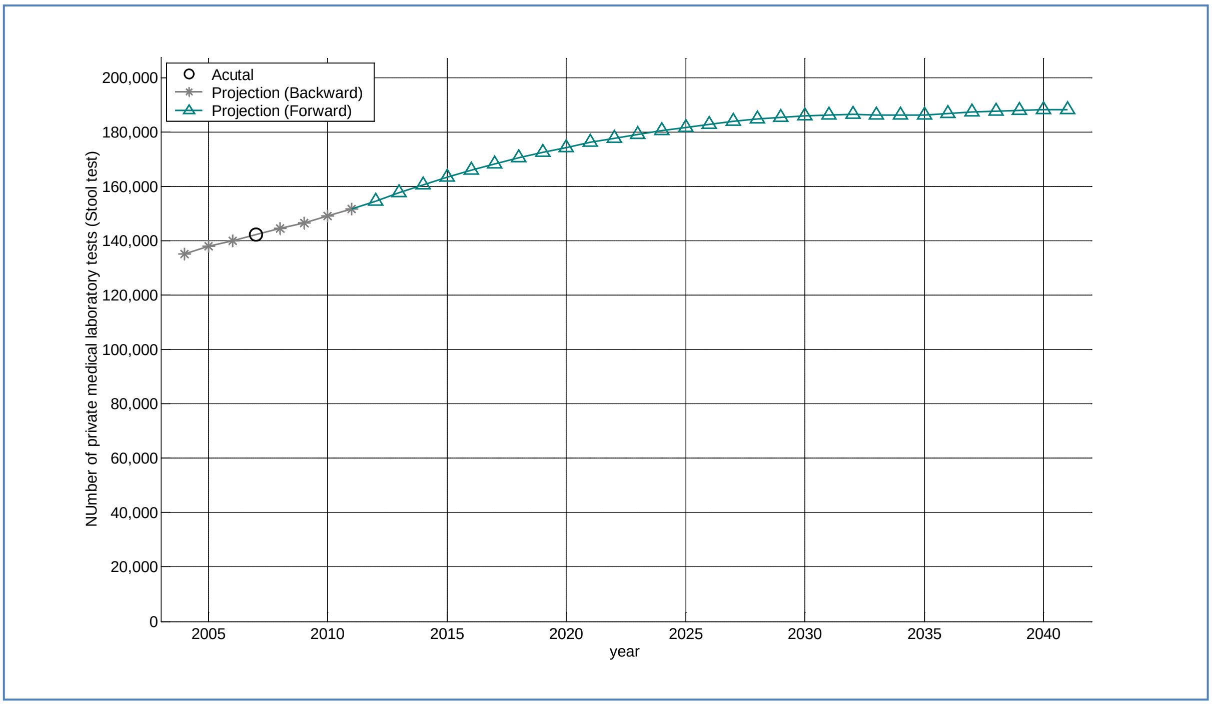

Figure 4.42 Historical and projected number of private laboratory stool tests

Pap smear

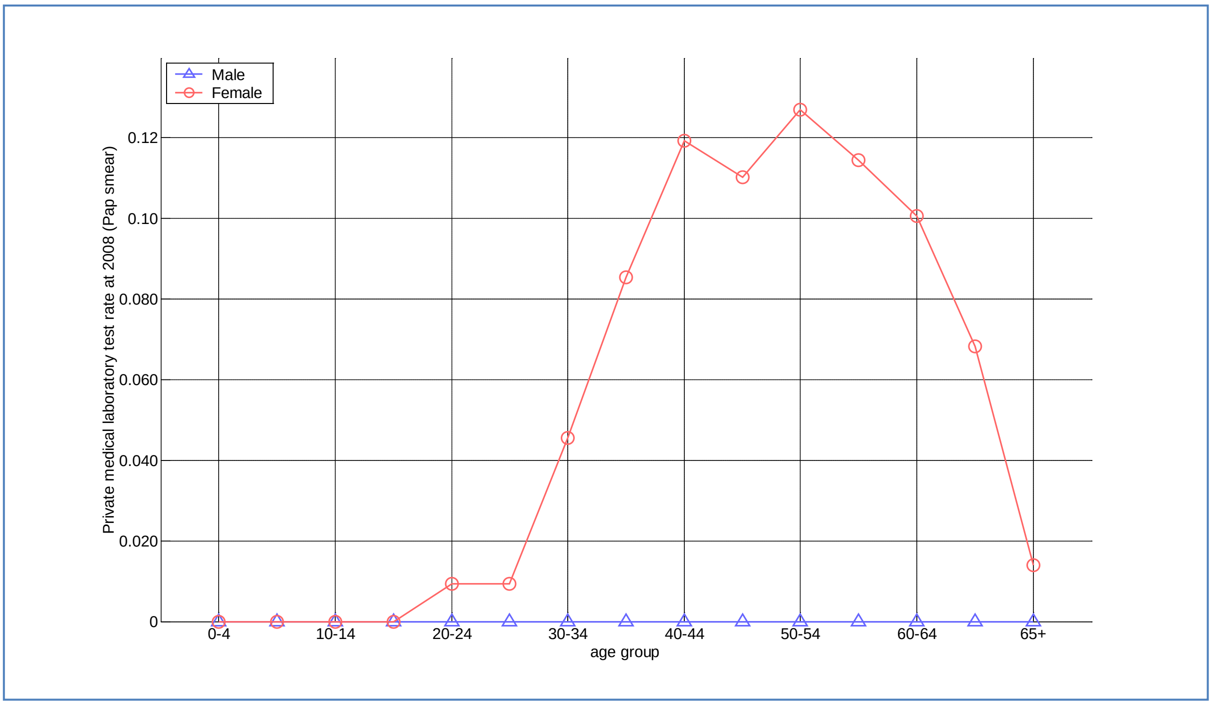

Figure 4.43 Private laboratory age, sex- Pap smear rate at 2008

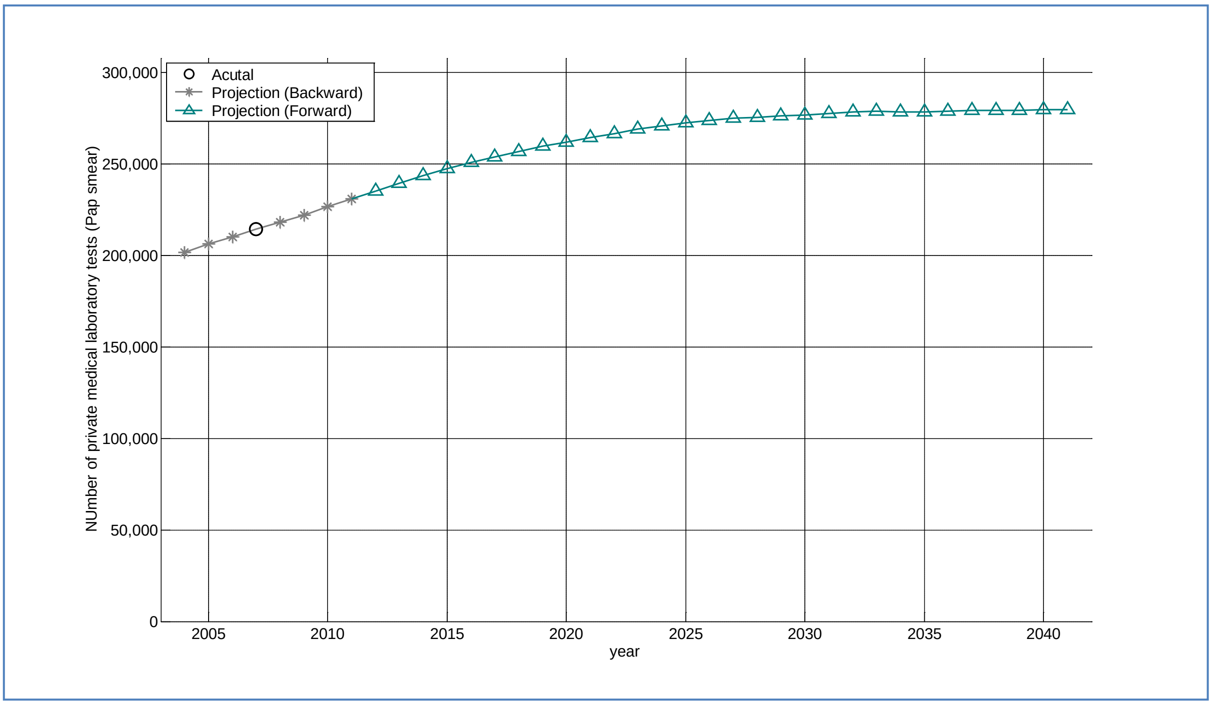

Figure 4.44 Historical and projected number of private laboratory Pap smears

4.2.2.2 Private hospitals

Demand for MLTs in private hospitals is expressed as a linear proportion of the number of laboratory tests proxied by the number of laboratory tests projected for each of the nine HA categories of tests, and generalized as a weighted sum of three healthcare utilisation volumes. The number of private hospital bed-days and the number of private hospital outpatient visits are linearly proportional to the number of private hospital discharges (Figure 4.46 and 4.47)

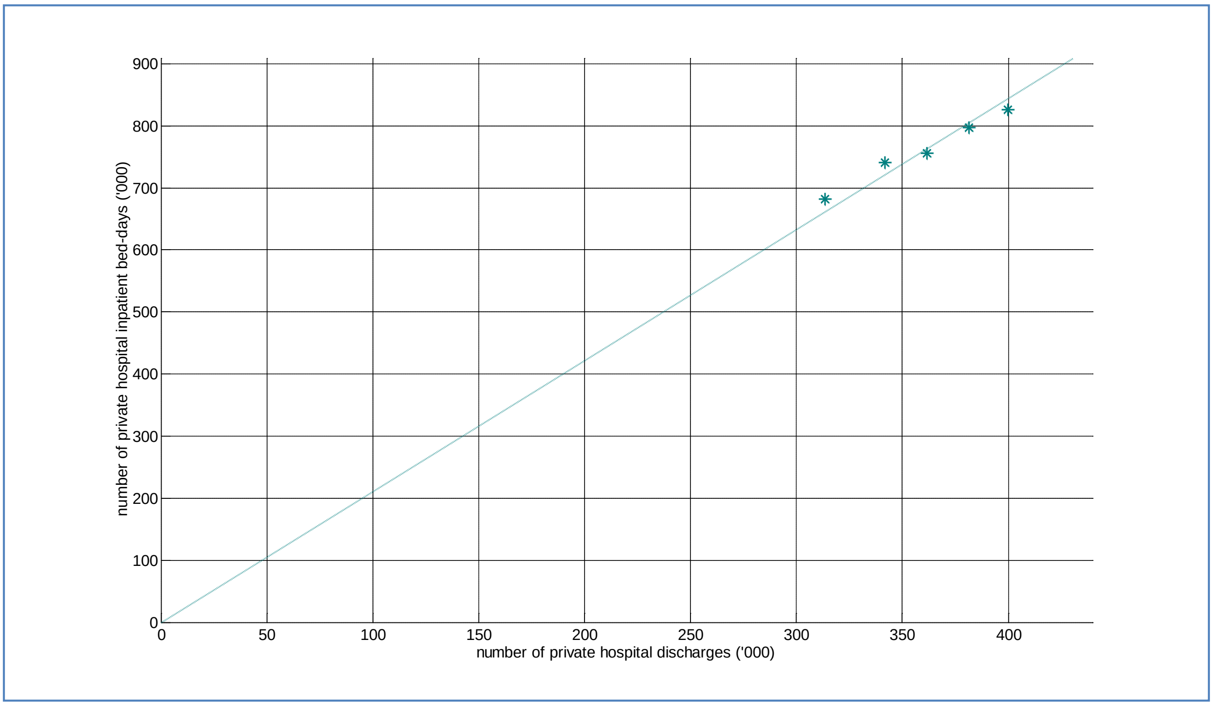

Figure 4.45 Number of private hospital inpatient bed-days by the number of private hospital discharges

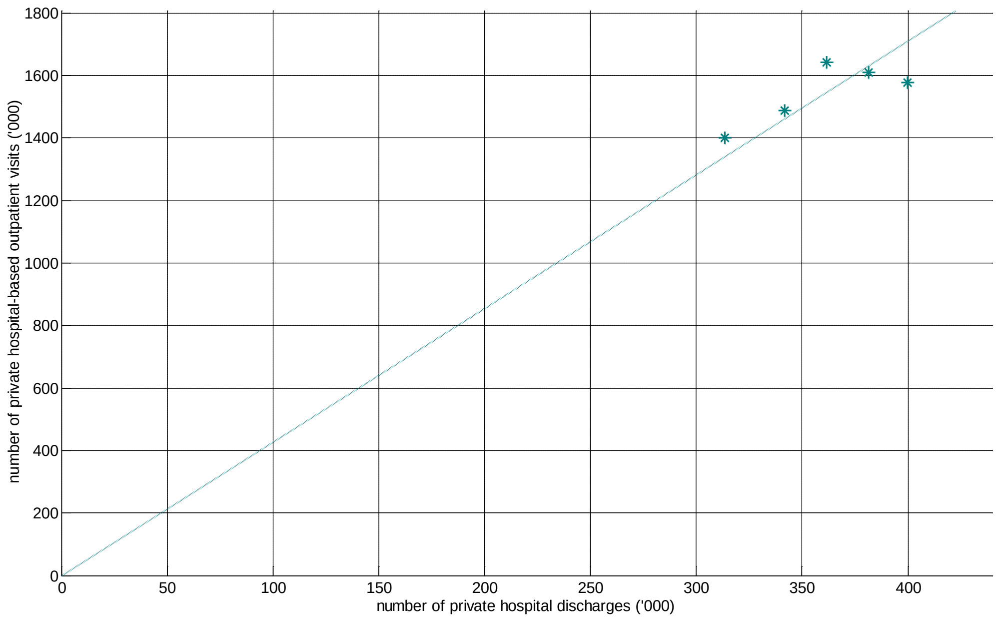

Figure 4.46 Number of private hospital-based outpatient visits by the number of private hospital discharges

4.2.3 Academic sector

The academic sector MLT demand projection is based on the number of students in the medical laboratory technician degree programme as provided by The Hong Kong Polytechnic University (2003 – 2013) and the number of MLTs employed in the academic research sector (university research laboratories). The number of students in MLT training programmes is held constant from 2019 (Figure 4.48).

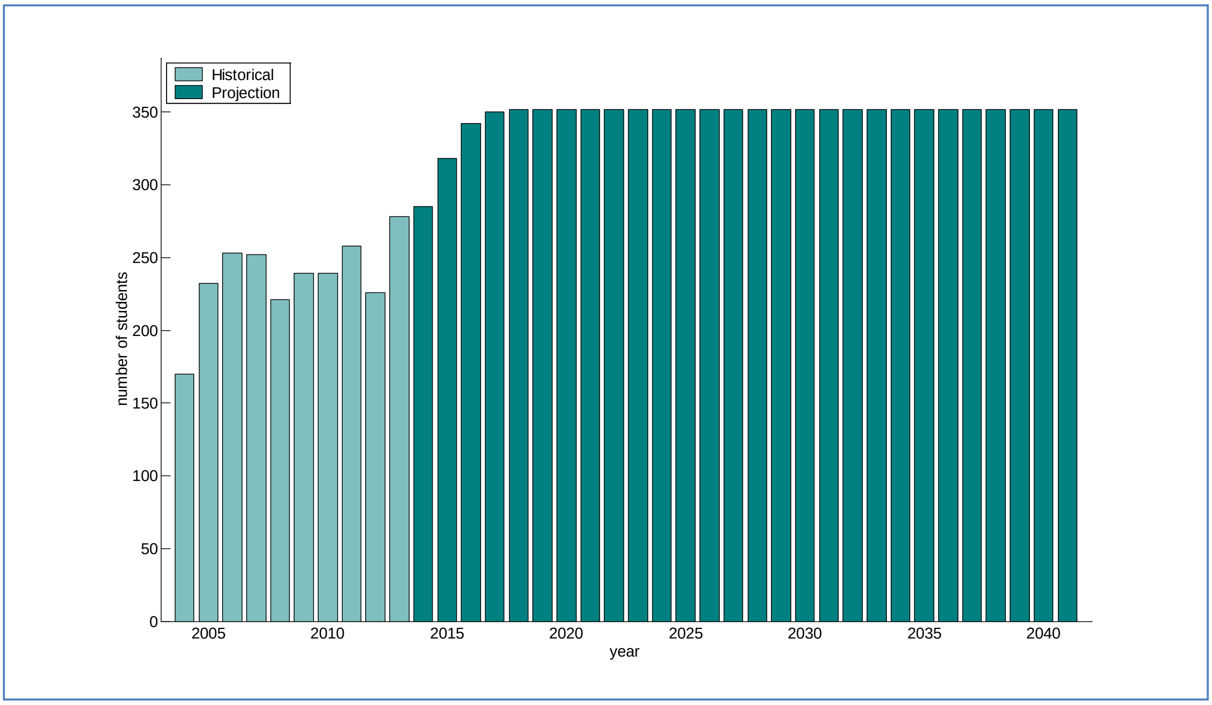

Figure 4.47 Historical and projected number of students in MLT training programmes (2005-2041)

4.3 Converting healthcare utilisation to full time equivalents (FTEs)

Two regression-based approaches are used to convert healthcare demand/utilisation to MLT FTE by service sector (public (HA and DH), private), and by service type (in-patient vs. outpatient). FTE is expressed as a linear combination of the utilisation measures.

4.3.1 Medical laboratory technologist FTEs - Public sector

4.3.1.1 Hospital Authority

The number of HA medical laboratory technologists is expressed as a linear proportion to the number of laboratory tests by test type or category and by service sector (inpatient or outpatient).

Test type or category (C^i)	**Inpatient discharge**	**Inpatient acute care bed-day**	**Specialist outpatient visit**
1. Haematology	✓		✓
2. Blood banking	✓		✓
3. Microbiology	✓		✓
4. Histopathology / Cytology	✓		✓
5. Chemical pathology		✓	✓
6. Immunology		✓	
7. Other pathology	✓		✓

$$C_{HA}^{1} = D_{HA} + S_{HA}$$
$$C_{HA}^{2} = D_{HA} + S_{HA}$$
$$C_{HA}^{3} = 0.9D_{HA} + 0.1S_{HA}$$
$$C_{HA}^{4} = D_{HA} + S_{HA}$$
$$C_{HA}^{5} = 0.6B_{HA} + 0.4S_{HA}$$
$$C_{HA}^{6} = B_{HA}$$
$$C_{HA}^{7} = D_{HA} + S_{HA}$$

where D_{HA} number of HA discharges,

B_{HA} number of HA acute inpatient bed-days

S_{HA} number of HA specialist outpatient visits.

The FTE workload coefficient α_{HA}^{i} is the number of MLT FTEs per laboratory test:-

$$\alpha_{HA}^{i} = \frac{number\ of\ MLT\ FTEs\ involved\ in\ the\ i^{th}\ laboratory\ test}{number\ of\ i^{th}\ laboratory\ test}$$

A time series analysis was used to obtain the projected workload coefficients (Figure 4.49 – 4.55), and hence converted to the required number MLT FTEs (Figure 4.56 – 4.63).

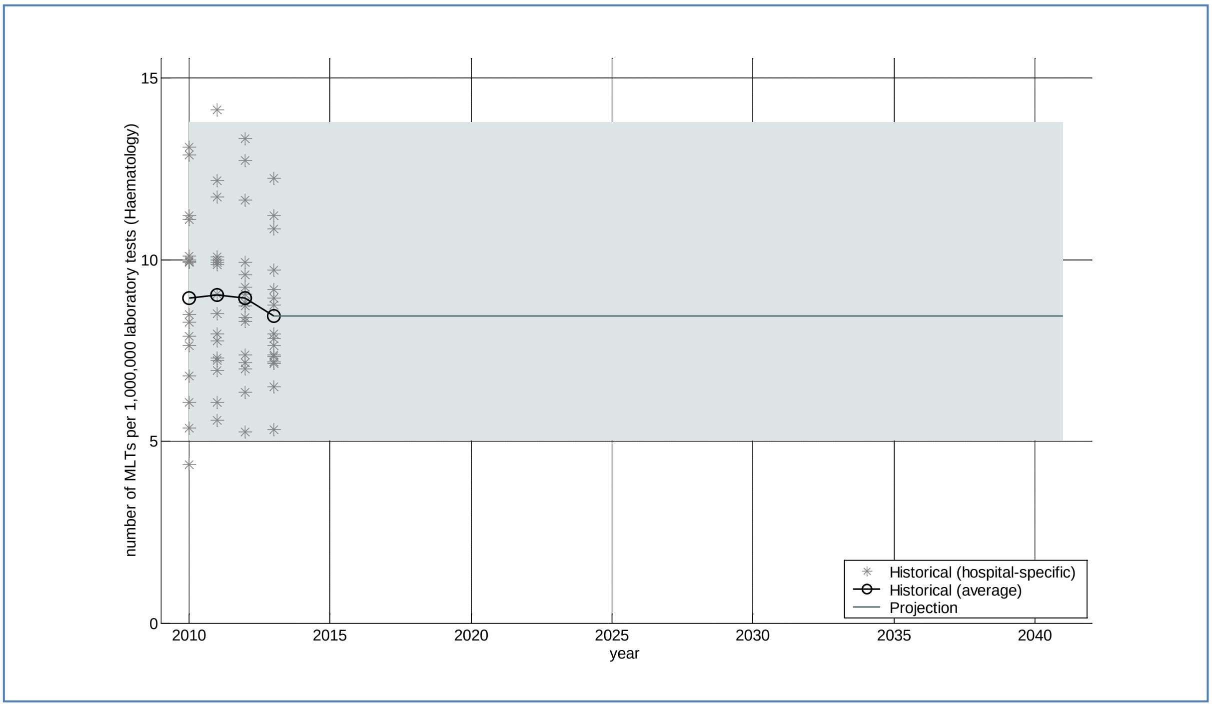

Figure 4.48 Historical and projected number of MLTs per 1,000,000 HA haematology laboratory tests

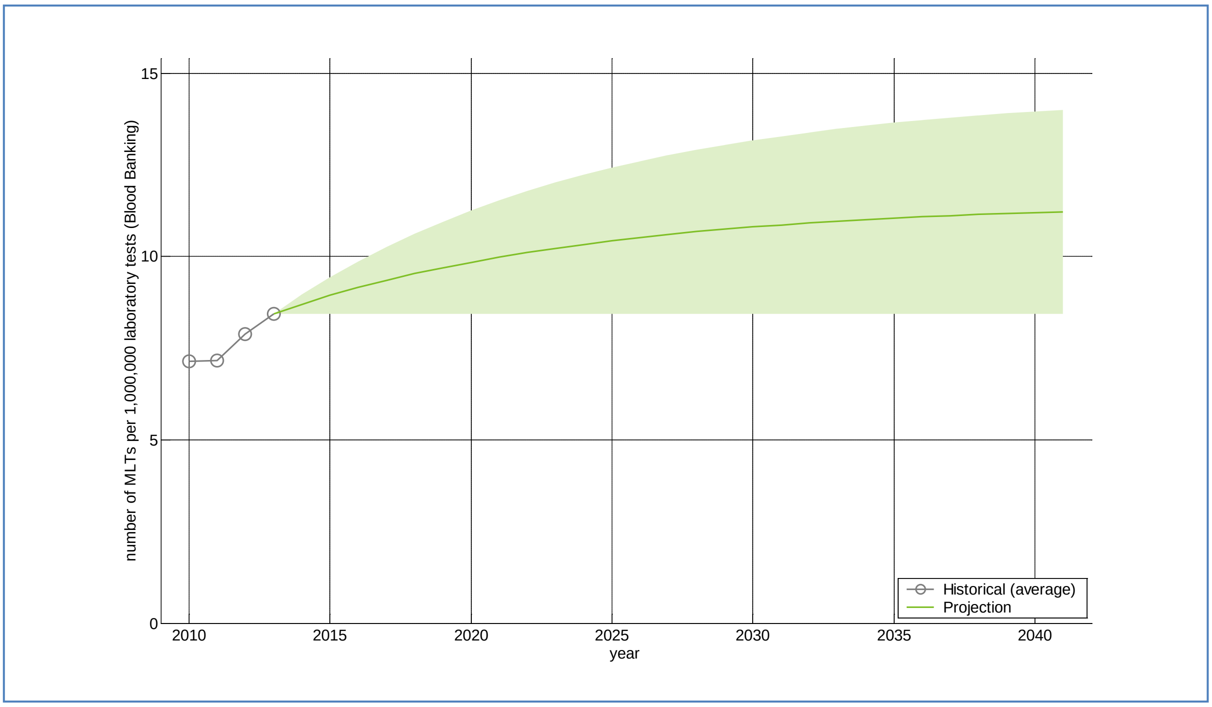

Figure 4.49 Historical and projected number of MLTs per 1,000,000 HA blood banking laboratory tests

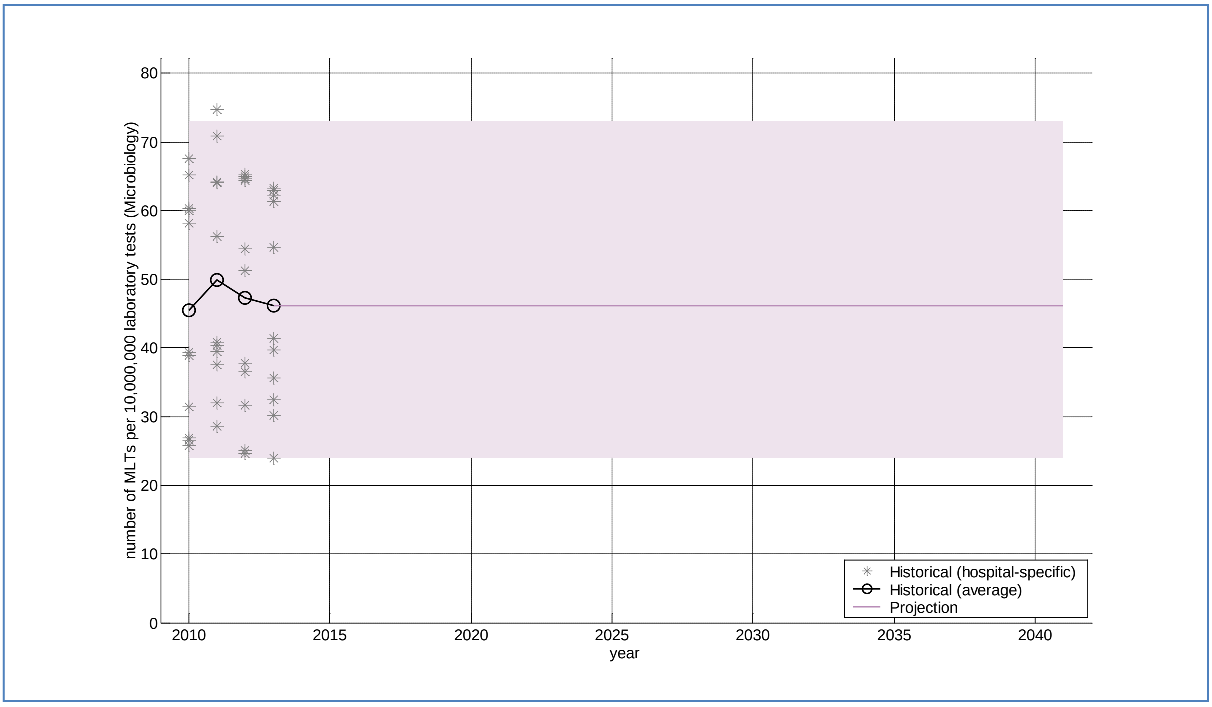

Figure 4.50 Historical and projected number of MLTs per 10,000,000 HA microbiology laboratory tests

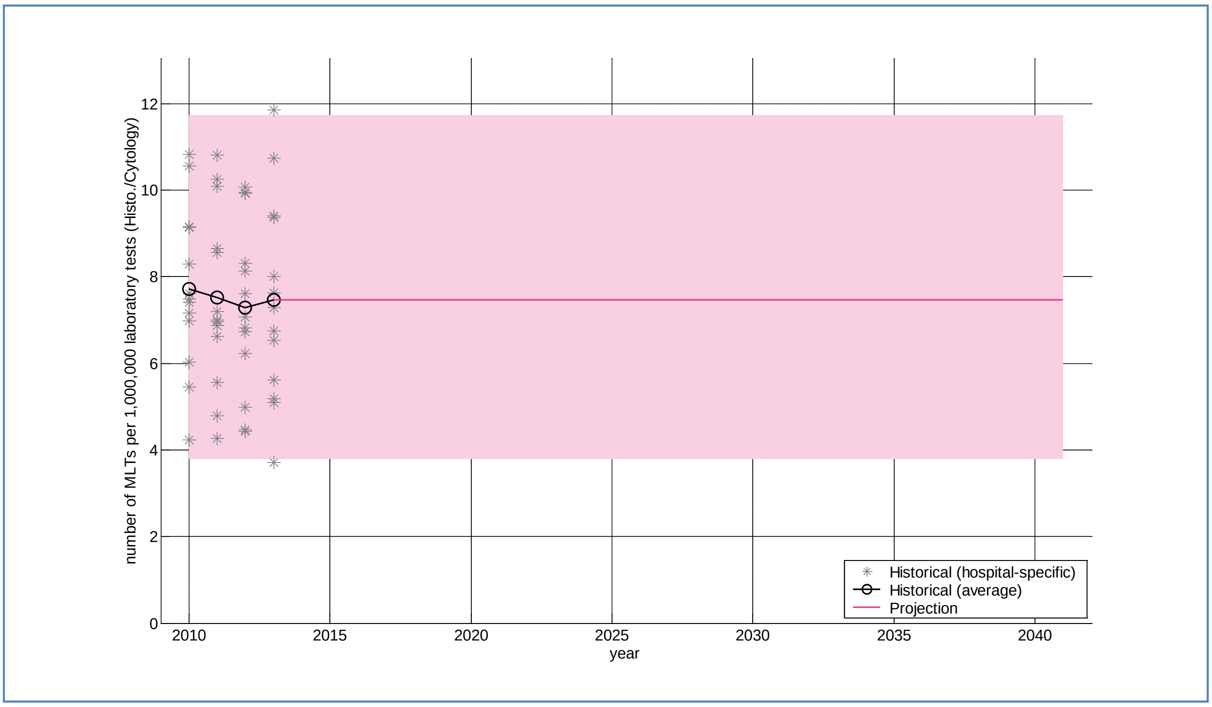

Figure 4.51 Historical and projected number of MLTs per 1,000,000 HA histopathology / cytology laboratory tests

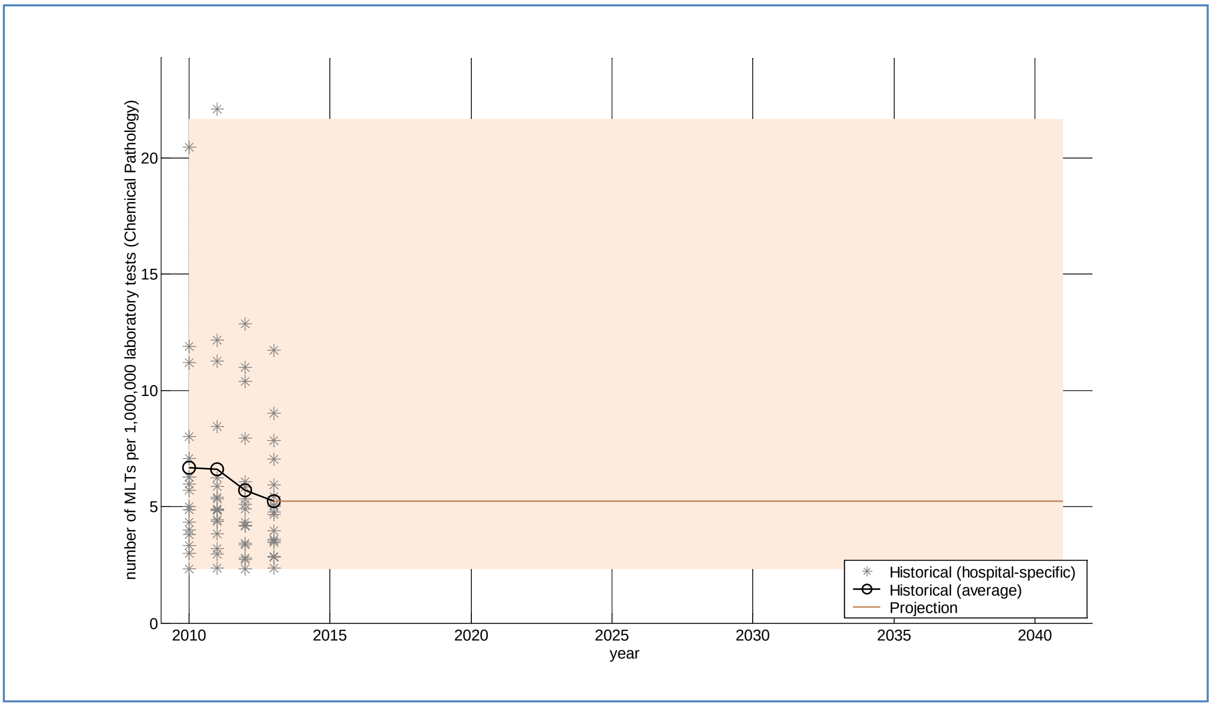

Figure 4.52 Historical and projected number of MLTs per 1,000,000 HA chemical pathology laboratory tests

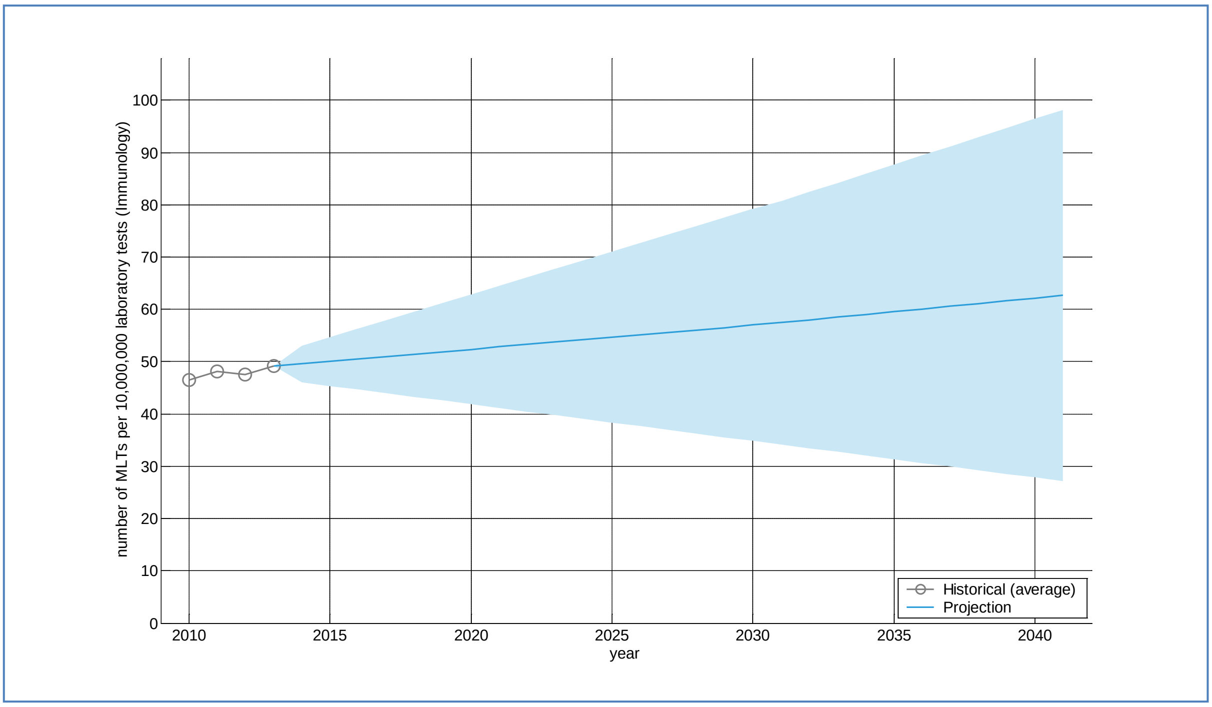

Figure 4.53 Historical and projected number of MLTs per 10,000,000 HA immunology laboratory tests

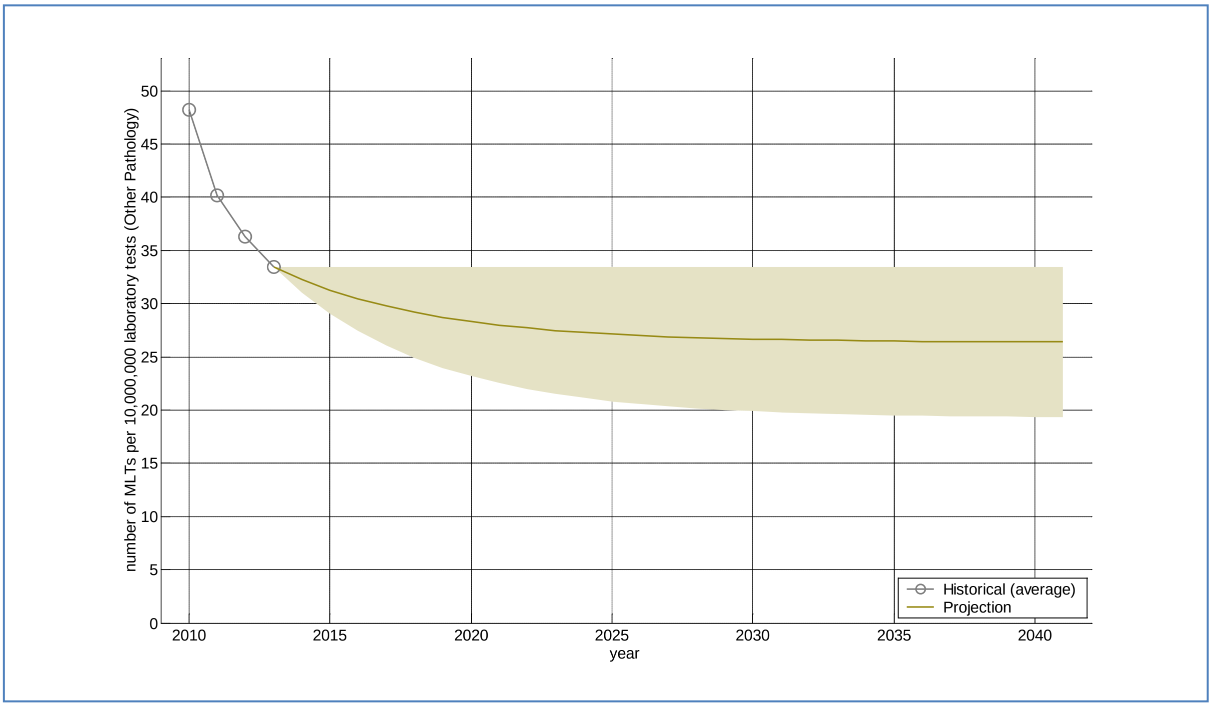

Figure 4.54 Historical and projected number of MLTs per 10,000,000 HA other pathology laboratory tests

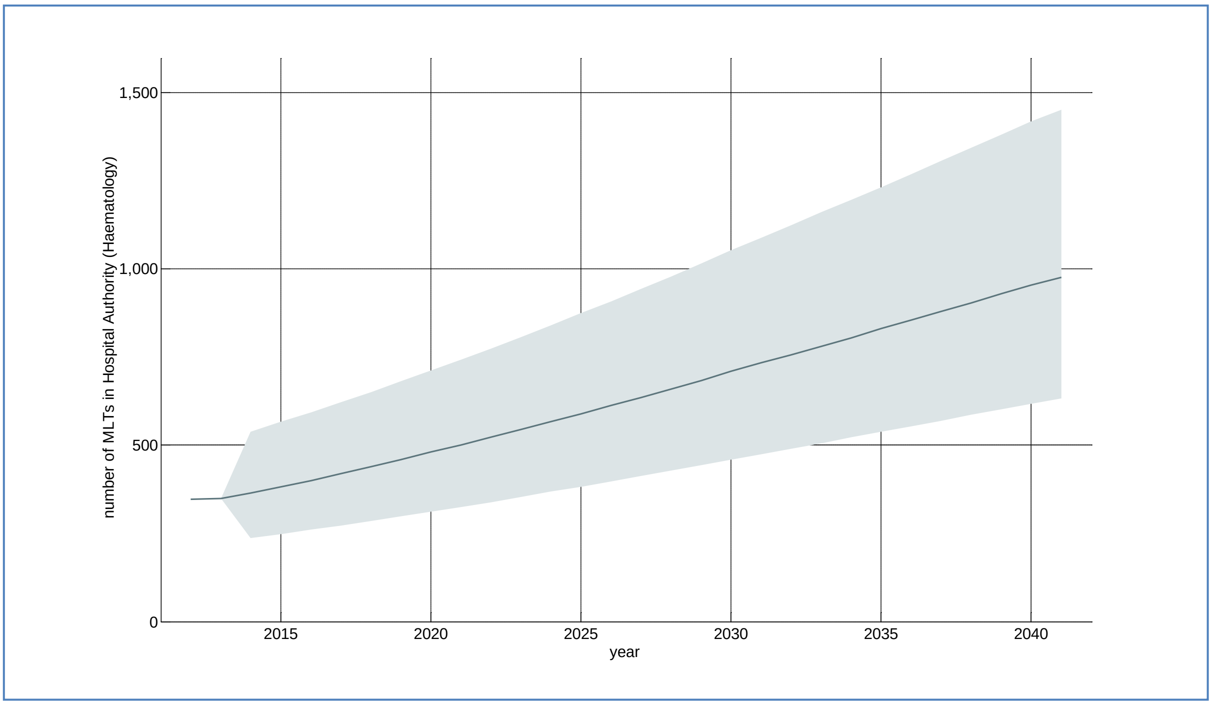

Figure 4.55 Historical and projected number of MLTs in HA: Haematology

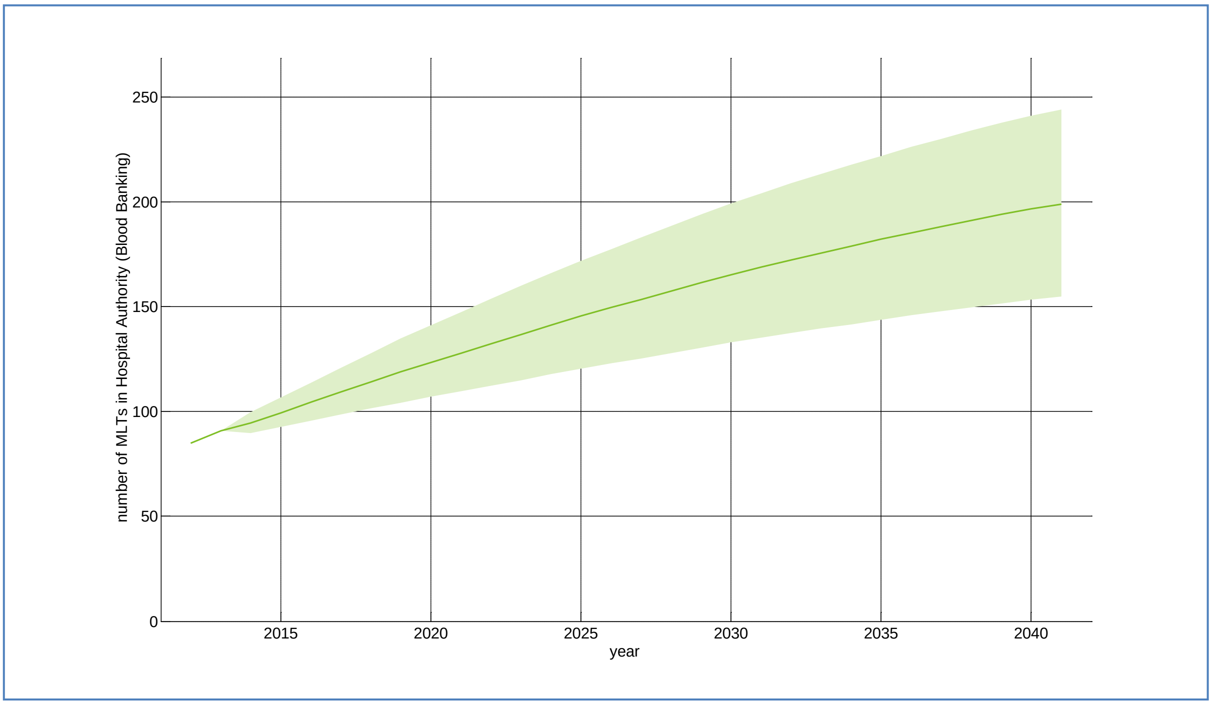

Figure 4.56 Historical and projected number of MLTs in HA: Blood banking

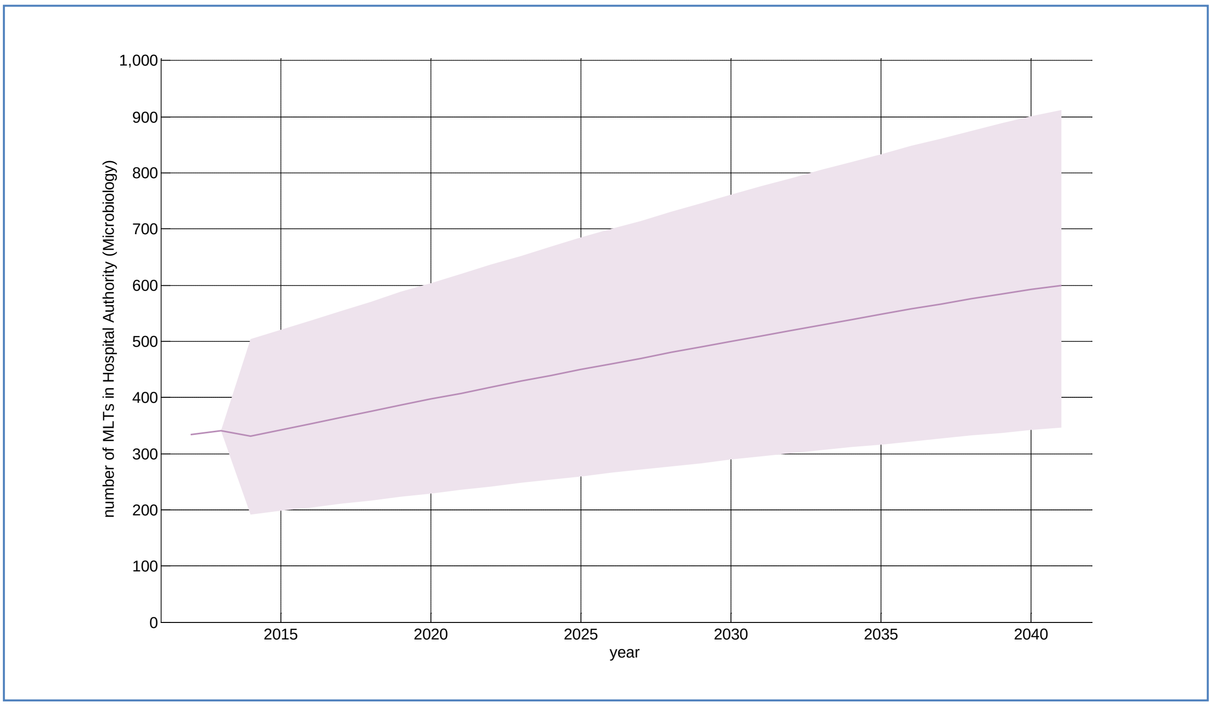

Figure 4.57 Historical and projected number of MLTs in HA: Microbiology

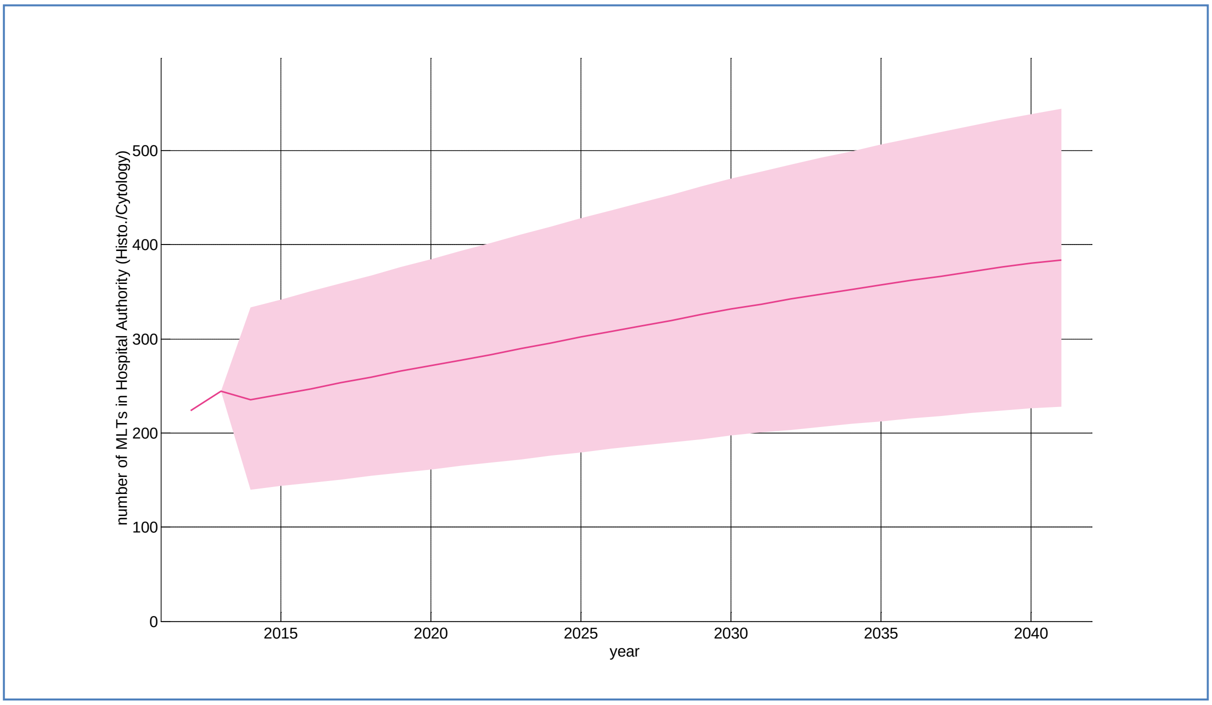

Figure 4.58 Historical and projected number of MLTs in HA: Histopathology / Cytology

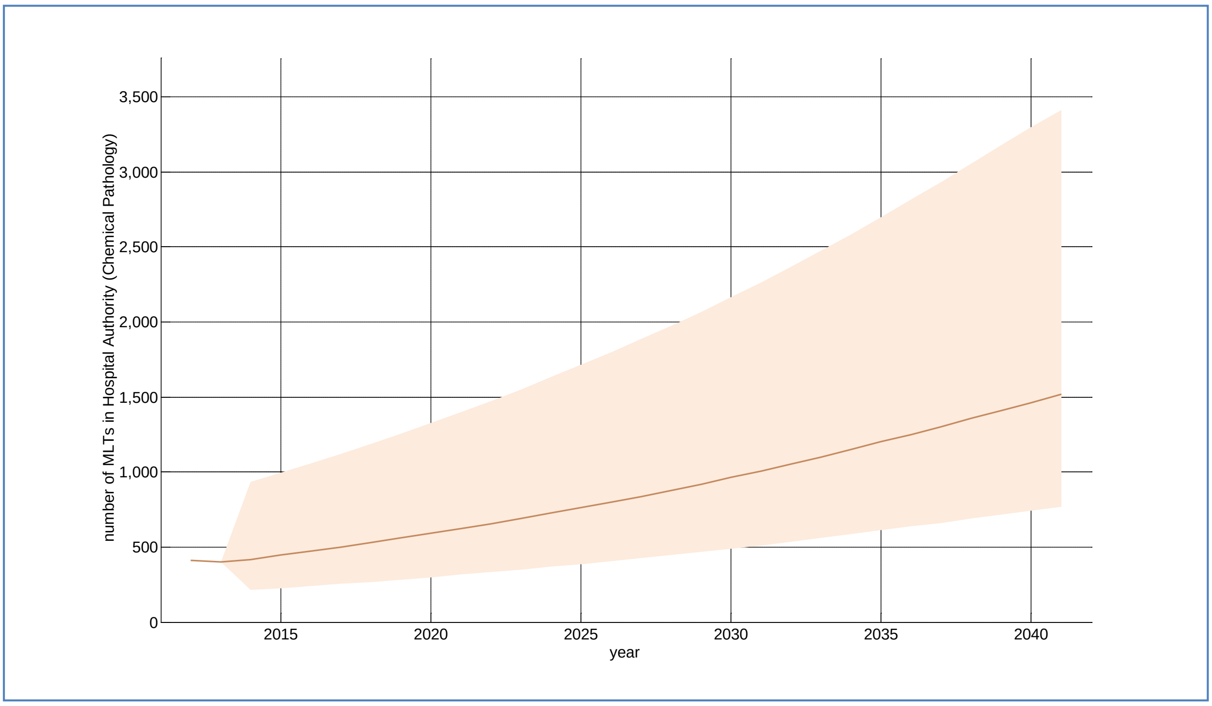

Figure 4.59 Historical and projected number of MLTs in HA: Chemical pathology

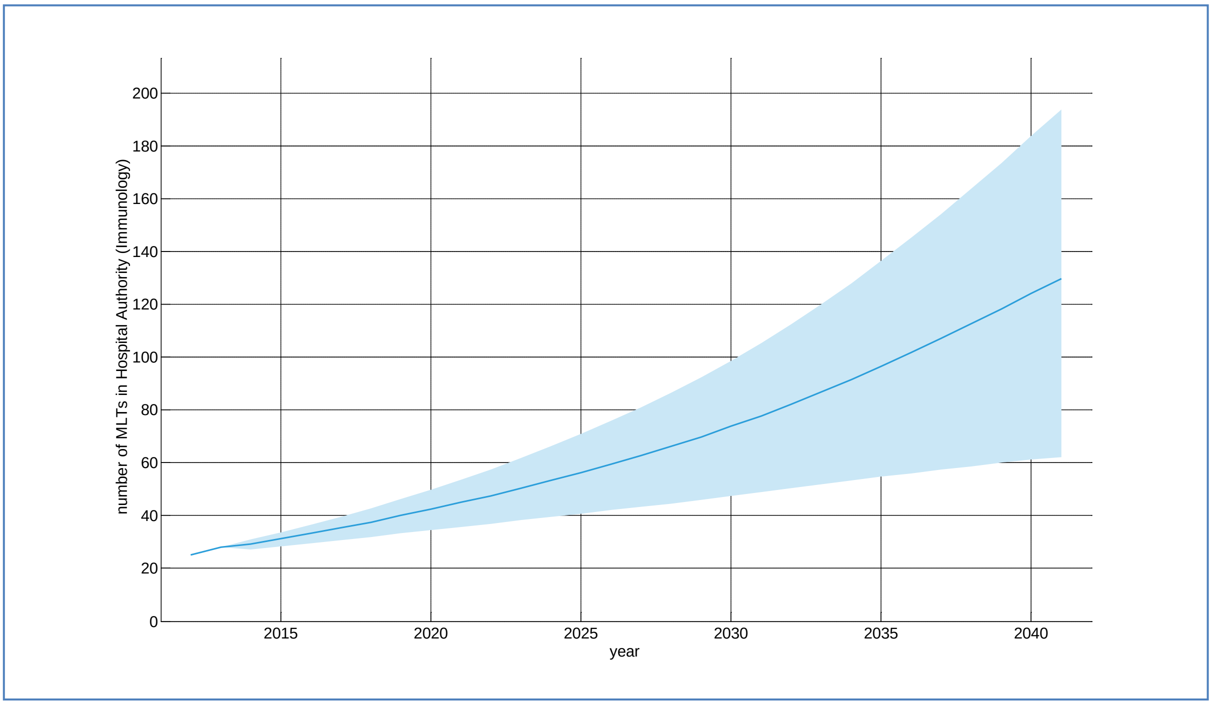

Figure 4.60 Historical and projected number of MLTs in HA: Immunology

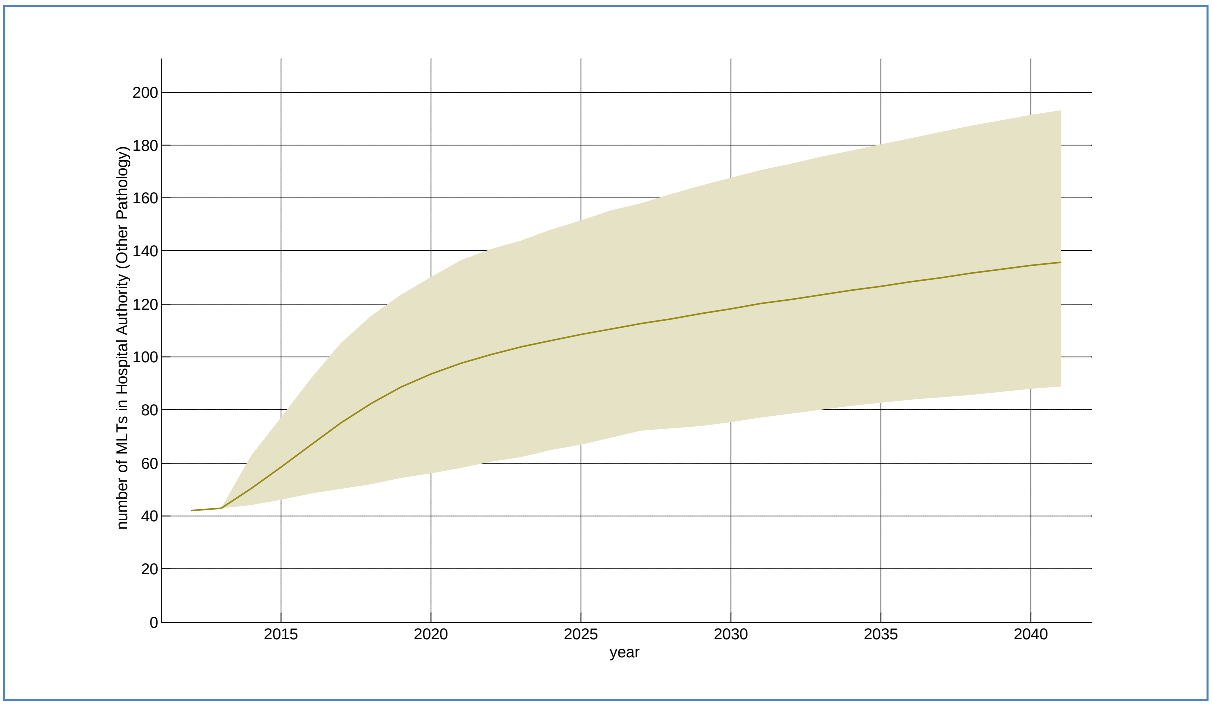

Figure 4.61 Historical and projected number of MLTs in HA: Other pathology

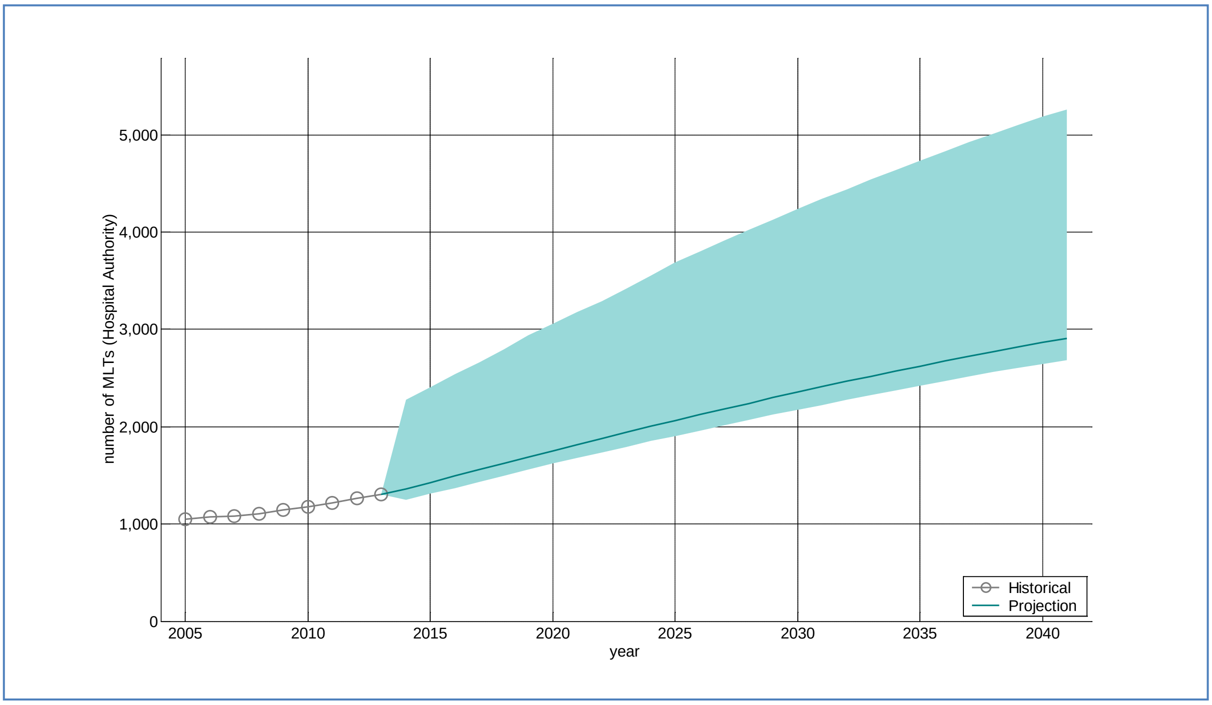

Figure 4.62 Historical and projected number of MLT FTEs in Hospital Authority

4.3.1.2 Department of Health

The number of MLTs in the Department of Health, F_{DH}, is expressed as a linear proportion of the number of DH laboratory tests:-

$$F_{DH} = \sum_{i=1}^{6} T_{DH}^{i} \times \alpha_{DH}^{i}$$

where i laboratory test index (i.e. i = 1 for 'Haematology, i = 2 for 'Chemical pathology, i = 3 for 'Microbiology, i = 4 for 'Histopathology, i = 5 for 'Cytology, i = 6 for 'Clinical Immunology),

T_{DH}^{i} number of the laboratory tests i

α_{DH}^{i} MLT FTEs per laboratory test i.

As only the aggregated number of DH MLTs is available, the projected sector-, and laboratory test-specific workload coefficients $\{\alpha_{DH}^{i}\}$ reference HA coefficients. The coefficients are adjusted for between sector differences by an FTE workload-scaling factor φ:-

Haematology:	$\alpha_{DH}^{1} = \varphi \times \alpha_{HA}^{1}$
Chemical pathology:	$\alpha_{DH}^{2} = \varphi \times \alpha_{HA}^{5}$
Microbiological:	$\alpha_{DH}^{3} = \varphi \times \alpha_{HA}^{3}$
Histopathology:	$\alpha_{DH}^{4} = \varphi \times \alpha_{HA}^{4}$
Cytology:	$\alpha_{DH}^{5} = \varphi \times \alpha_{HA}^{4}$
Clinical immunology:	$\alpha_{DH}^{6} = \varphi \times \alpha_{HA}^{6}$

Although DH MLT FTEs workload scaling factor declines (Figure 4.64) the number of MLT FTEs are projected to increase slowly (Figure 4.65).

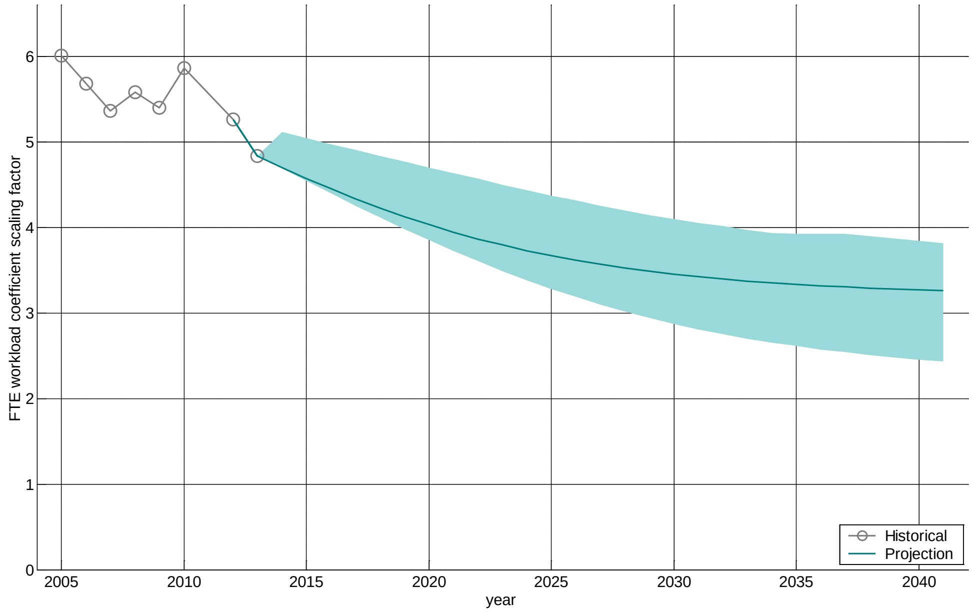

Figure 4.63 FTE workload scaling factor

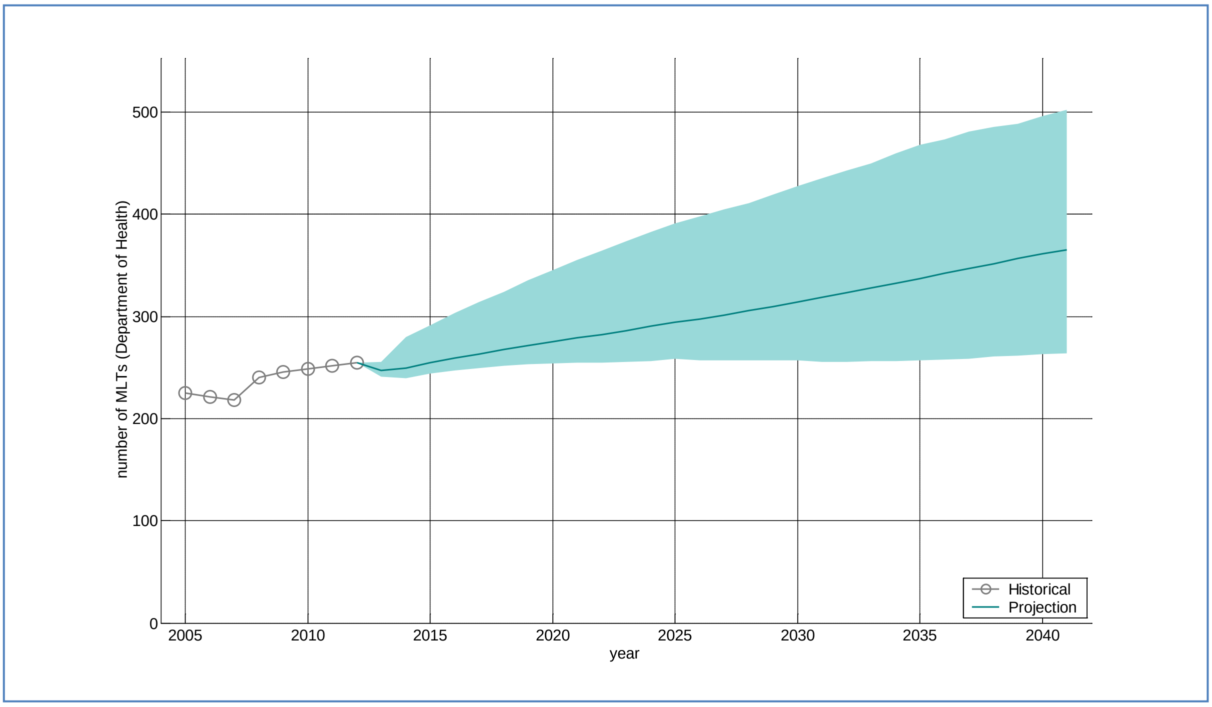

Figure 4.64 Projected number of MLT FTEs in Department of Health

4.3.2 Medical laboratory technologist FTEs - Private sector

4.3.2.1 Medical clinics/laboratories

The MLT demand in private sector is expressed as a linear proportion of the number of private sector outpatient visits as follows:-

$$\begin{aligned} &Number\ of\ MLTs\ in\ private\ sector\ (F_{Private}) \\ &\quad = Number\ of\ private\ outpatient\ visits\ (v_{Private}) \\ &\quad \times\ Number\ of\ MLT\ \ per\ private\ outpatient\ visit\ (\alpha_{Private}) \end{aligned}$$

The number of FTE medical laboratory technologists per private outpatient visit is projected to remain stable (Figure 4.66) whereas the number of FTE medical laboratory technologists in private outpatient setting is projected to increase slowly (Figure 4.67).

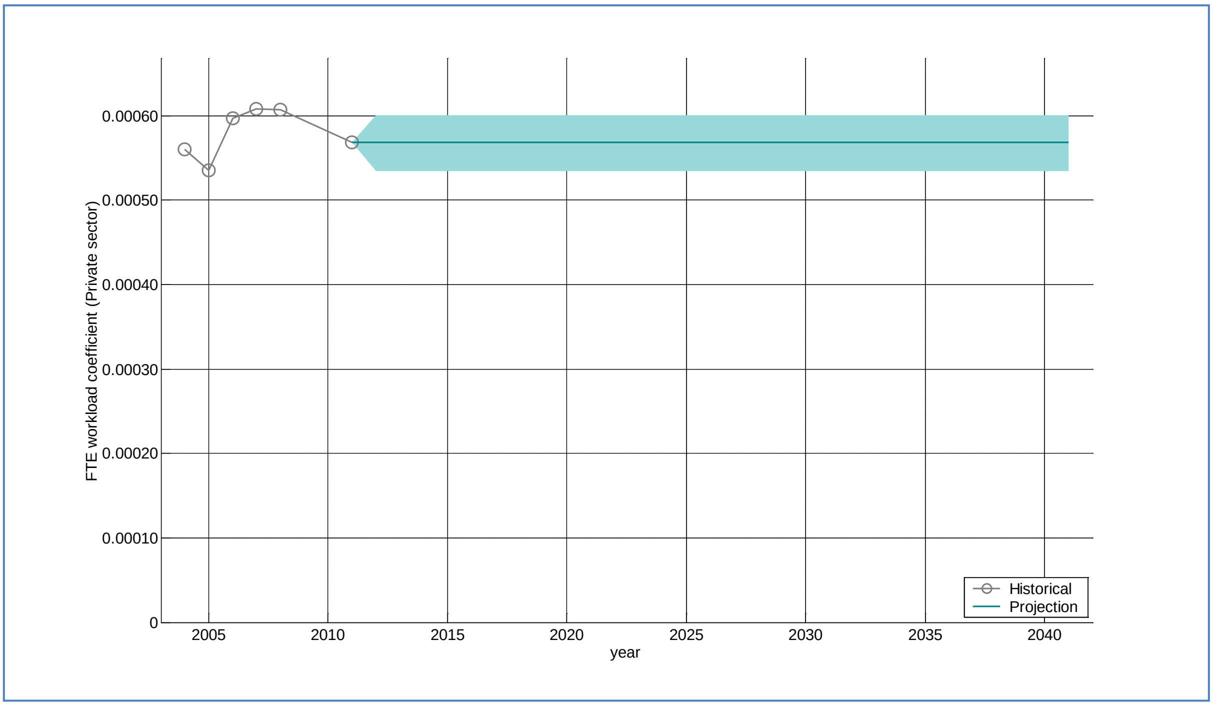

Figure 4.65 Historical and projected number of FTE medical laboratory technologists per private outpatient visit

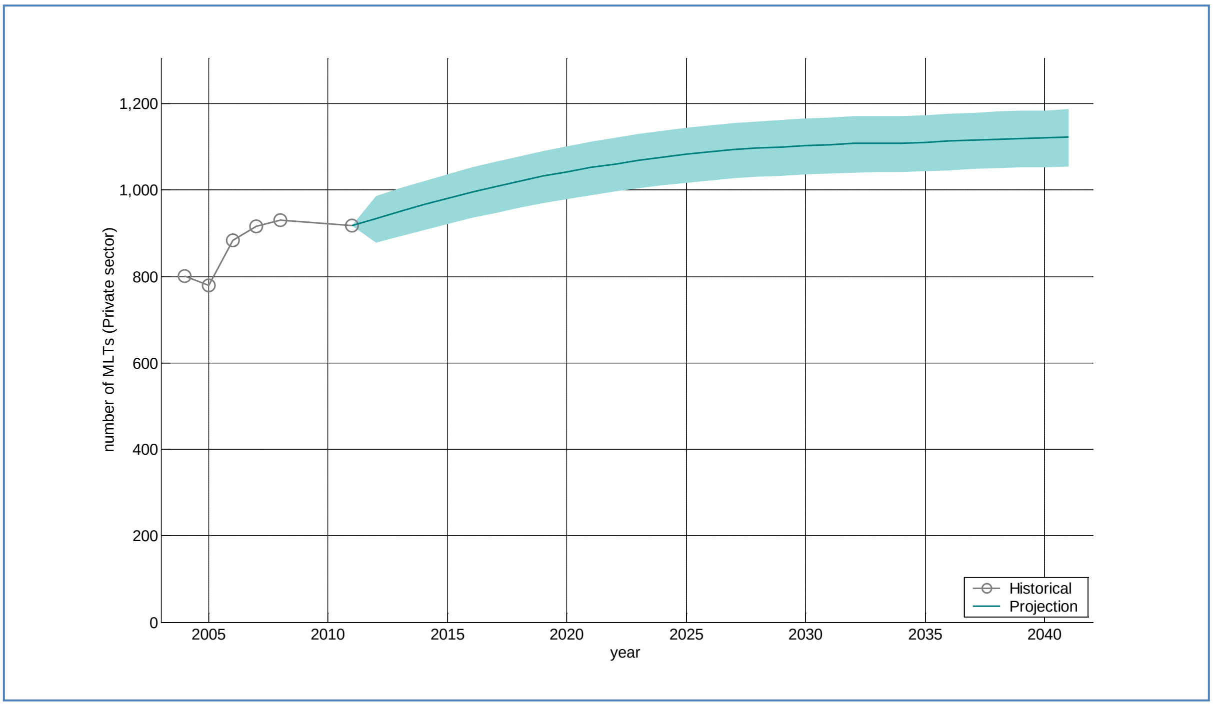

Figure 4.66 Historical and projected number of FTE medical laboratory technologists in private outpatient setting

4.3.2.2 Private hospitals

Although the number of MLT FTEs per private hospital discharge remain constant (Figure 4.68) the number of MLT FTEs are projected to increase slowly (Figure 4.69).

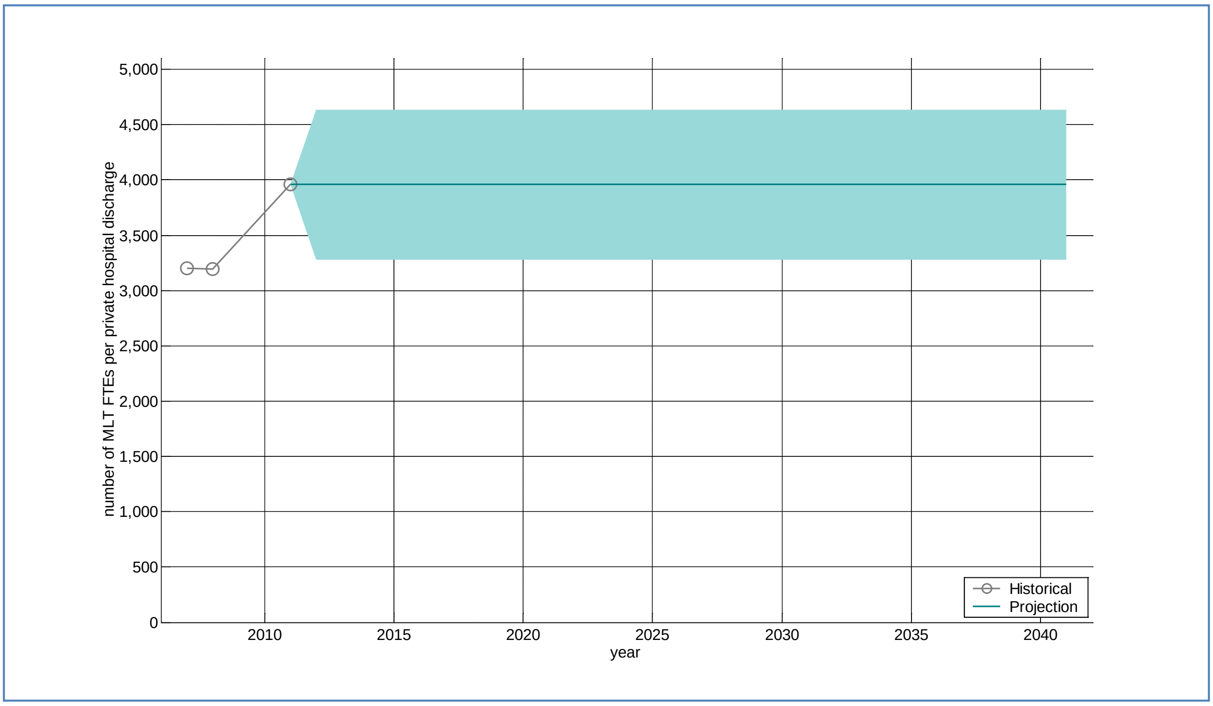

Figure 4.67 Historical and projected number of MLT FTEs per private hospital discharge

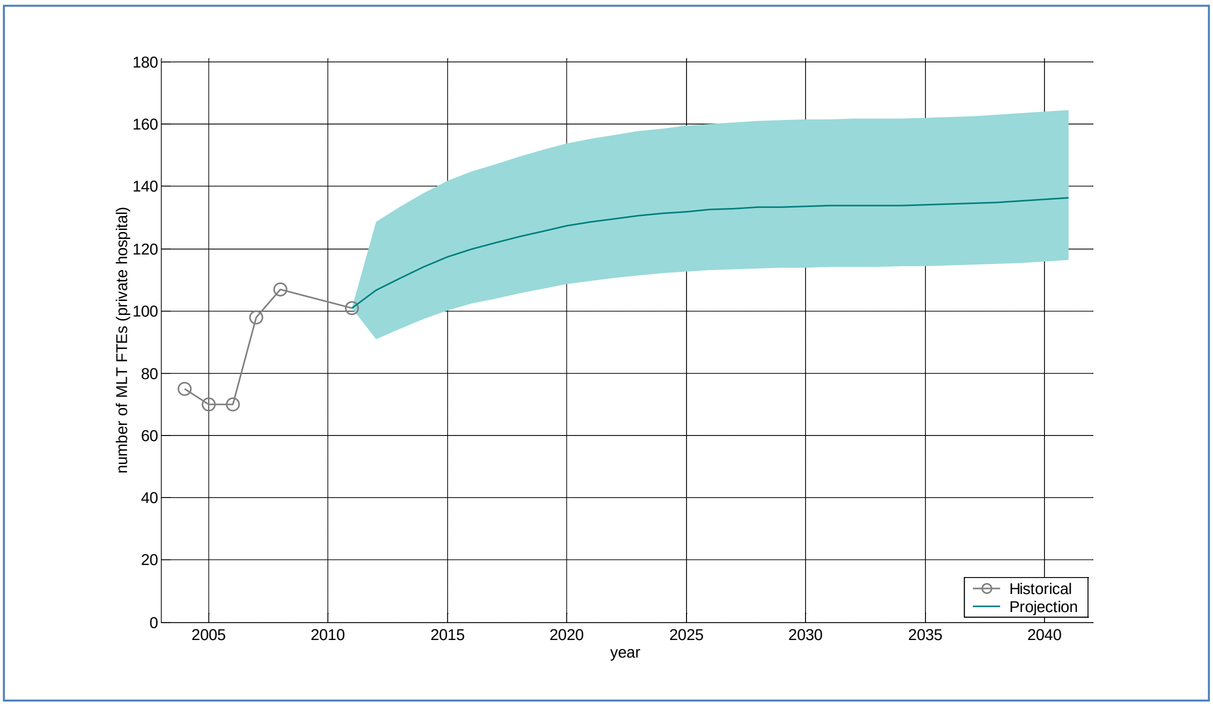

Figure 4.68 Historical and projected number of MLT FTEs in private hospital

4.3.3 Academic sector

For the academic sector, the demand for MLTs is linearly proportional to the number of MLT students as follows:-

$$\text{Number of MLTs in the academic sector} = \alpha_{university} \times \text{Number of MLT students in training programmes}$$

where $\alpha_{university}$ is the number of MLT FTEs per student.

There are 6 academic staffs with MLT registration involved in teaching at the Hong Kong Polytechnic University and 318 students. $\alpha_{academic}$ is $\frac{6}{318} = 0.018$. The projected number of MLTs involved academic sector teaching increases to 2018 and thereafter plateaus (Figure 4.70).

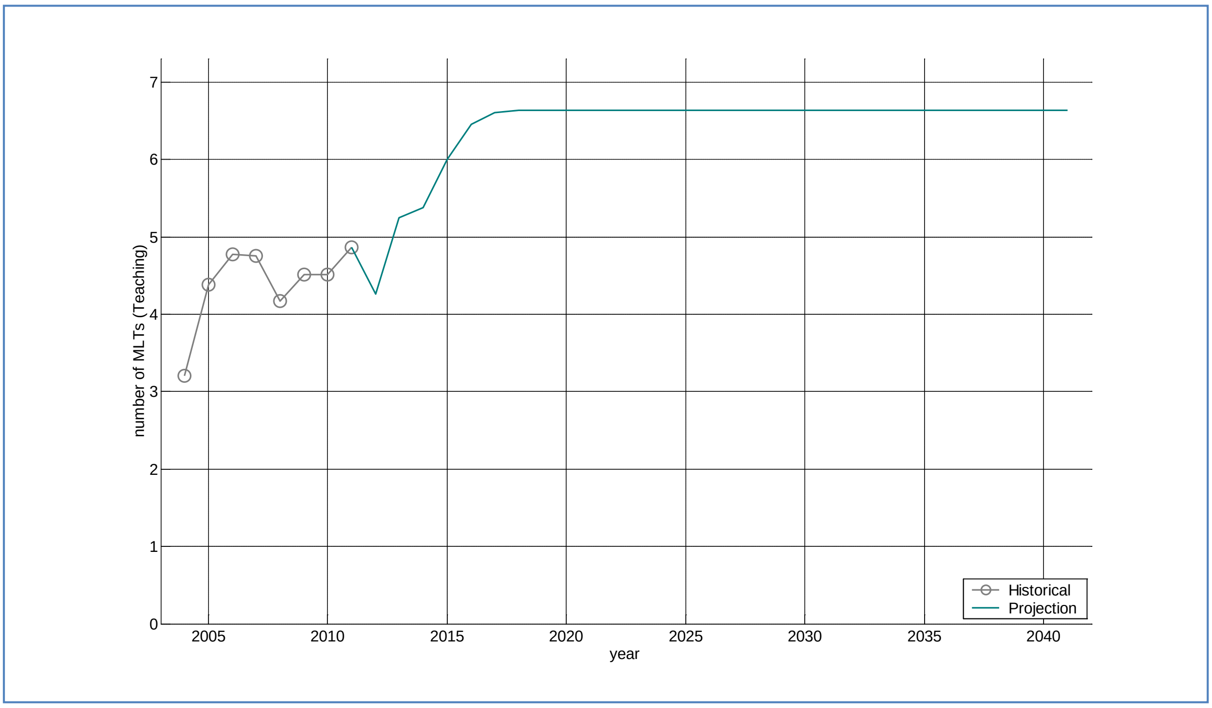

Figure 4.69 Historical and projected number of MLT FTE's involved in teaching (2004-2041)

MLTs also play active role in university research laboratories. A time series analysis based on historical data is used to project the number of MLTs in academic medical laboratories. The number of MLTs in academic medical laboratories is projected to steadily increase throughout the projection period (Figure 4.71).

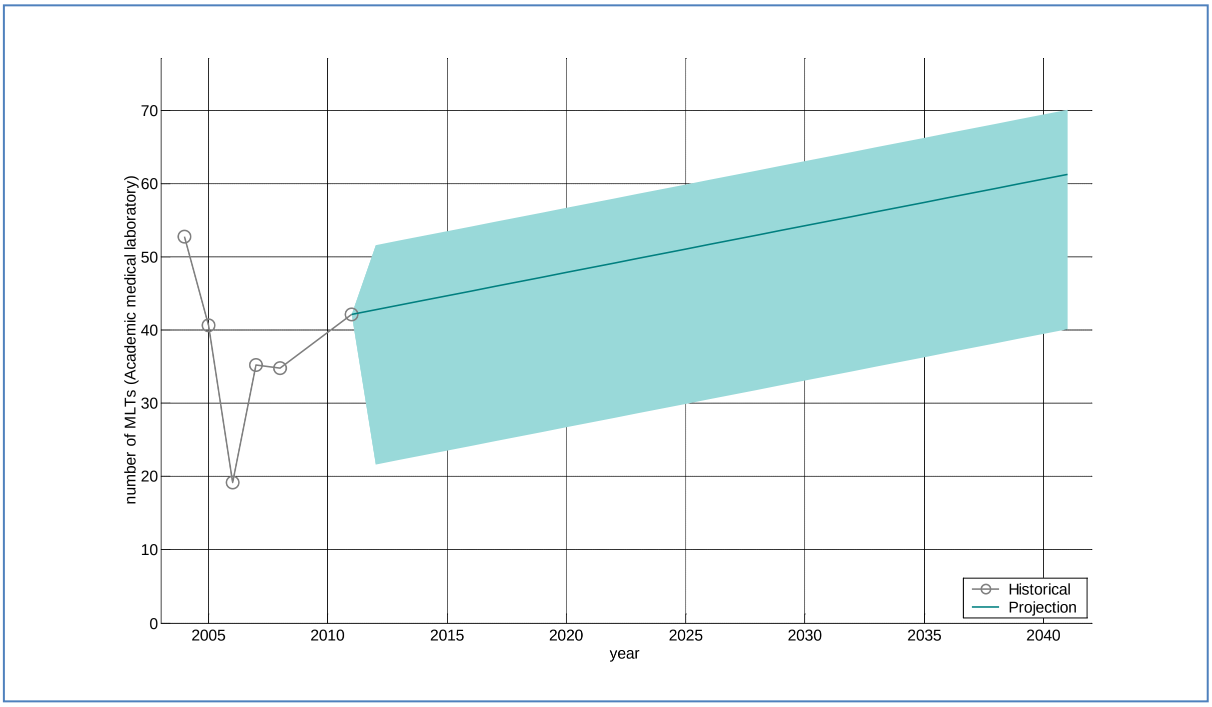

Figure 4.70 Projected number of MLT FTEs in academic medical laboratory

5 Projecting medical laboratory technologist supply

Data (age-, sex-specific) from the Medical Laboratory Technologists Board of the Supplementary Medical Professions (SMP) Council (the Council) for 2012 (155) is used for the MLT supply base case. Data from the Hong Kong Polytechnic University (PolyU), and the HKU School of Professional and Continuing Education (HKU SPACE) (156-157) and from the DH Health Manpower Survey (HMS) on MLT 2004-2008 & 2011 (158-163) are used for the supply projections.

5.1 Models for MLT supply

The MLT supply model is a non-homogenous Markov Chain Model (MCM)[4], where workforce systems are represented as “stocks and flows” (Figure 5.1). Flow refers to manpower supply over a period of time. Stock denotes manpower supply at a particular point in time.

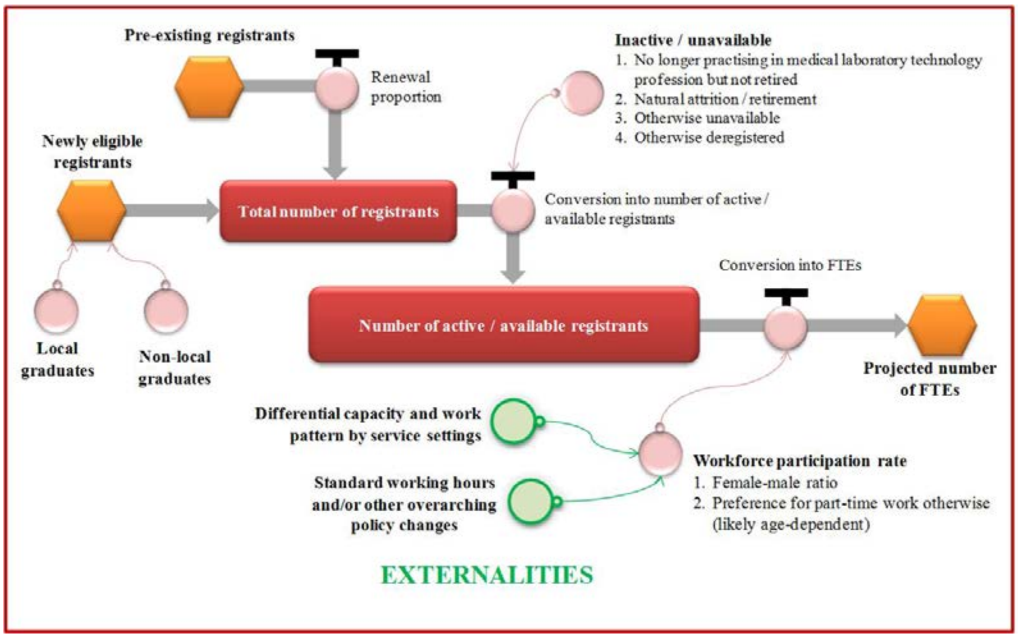

Figure 5.1 MLT supply model for Hong Kong.

There are five age-, sex-specific stocks by year (a,s,y) in the model:

n_{pre}	number of pre-existing registrants
n_{local}	number of local graduates
$n_{non\text{-}local}$	number of non-local graduates

[4]Markov Chain Model (MCM): MCM estimates transition probabilities relevant to manpower stock and flow and is useful for micro level manpower planning

$n_{current}$ number of current registrants

n_{active} number of active and available registrants

Flow in the supply model represents change in the stocks and is projected by determining

a) the number of current registrants (total number of local graduates, non-local graduates and pre-existing registrants):-

$$n_{current}(a,s,y) = p_{renewal}(y) \times n_{pre}(a,s,y) + n_{local}(a,s,y) + n_{non\text{-}local}(a,s,y)$$

where $p_{renewal}(y)$ is the licence renewal proportion at year *y*.

b) the number of active and available registrants:-

$$n_{active}(a,s,y) = n_{current}(a,s,y) \times p_{active}(a,s,y)$$

where $p_{active}(a,s,y)$ is the active proportion.

FTEs by service sector *c* at year *y* are calculated as:-

$$\text{FTE}(y,c) = \frac{\sum_a \sum_s n_{active}(a,s,y) \times p_{sector}(a,s,y,c) \times h(a,s,y,c)}{\text{Standard working hours per week per FTE}}$$

where $p_{sector}(a,s,y,c)$ is the proportion of MLT working in the service sector *c* at year *y*, and $h(a,s,y,c)$ is the average number of working hours per MLT.

The supply projection is based on the stocks and also the parameters $p_{renewal}(y)$, $p_{active}(a,s,y)$, $p_{sector}(a,s,y,c)$ and $h(a,s,y,c)$. A sigmoid model is used to project the parameters.

5.2 Determinants of supply: projecting stock and flow

5.2.1 Total number of registrants

The total number of registrants is defined as the number of pre-existing registrants (pool of registered MLT multiplied by the registration renewal proportion [97.9%, as provided by the

Council]) and the newly eligible registrants entering the pool by year (local graduates from PolyU and HKU SPACE; non-local graduates from the Council.)

The number of non-local graduates are projected using a sigmoid function based on the number of new non-local graduate registrations provided by the Council. The number of new registrants (local and non-local) entering the system are held constant at 210 every two years from 2019 – 2041 (Figure 5.2).

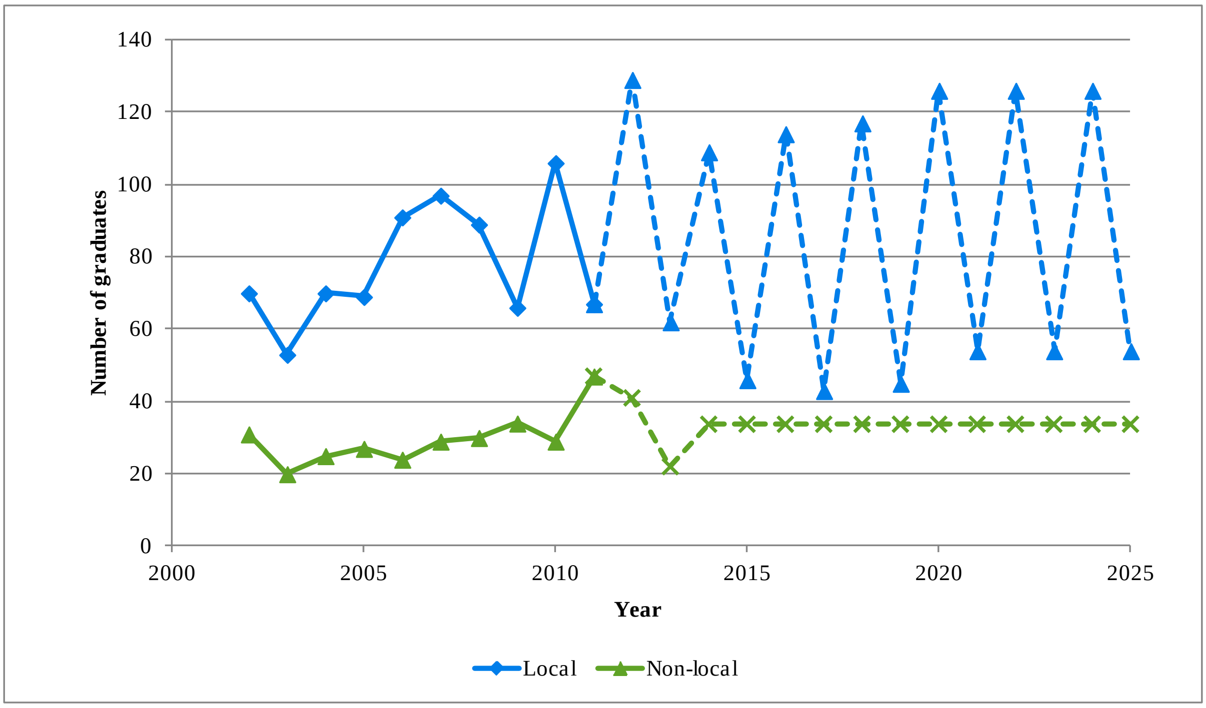

Figure 5.2 Number of newly eligible local and non-local registrants

5.2.2 Number clinically active

The number of clinically active/available registrants is more relevant for workforce projection than the total number of registrants in the MLT pool. The supply model stratifies clinically inactive/unavailable MLT by age into four categories: no longer practising in the MLT profession but not retired, natural attrition/retirement, otherwise unavailable, and otherwise deregistered. The five-year average proportion of clinically inactive/unavailable (based on data from the Council 2008-2012 and from HMS on MLT 2004-2008 & 2011) is applied to the projection.

5.2.2.1 No longer in practice but not retired

Based on HMS on MLT data, the proportion of MLTs (sex-stratified) 'no longer practising in the MLT profession but not retired' (clinically trained, qualified and registered MLTs who are no longer practising clinically) is projected to 2025 (Figure 5.3). The five-year average proportion is applied to the projection.

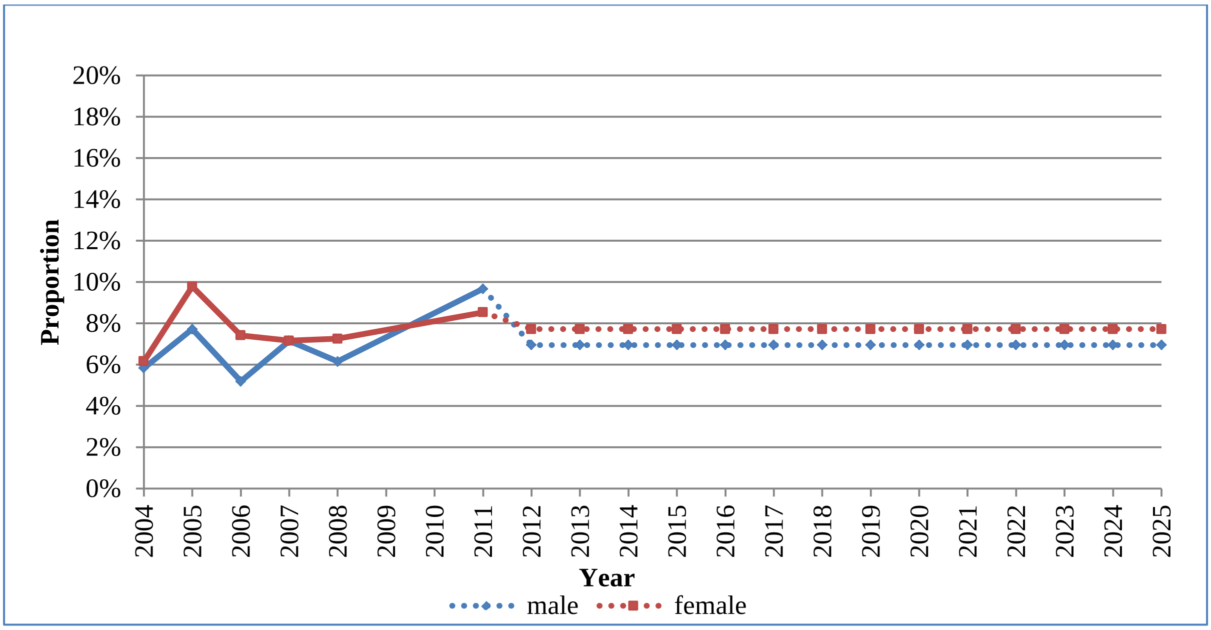

Figure 5.3 The proportion of MLTs 'no longer practising in the MLT profession but not retired' by sex (2012-2025)

5.2.2.2 Natural attrition/retirement

The natural attrition/retirement projections are age-, and sex-specific (Figure 5.4(a) and 5.4(b)). As expected, the projected retirement proportion increases by age.

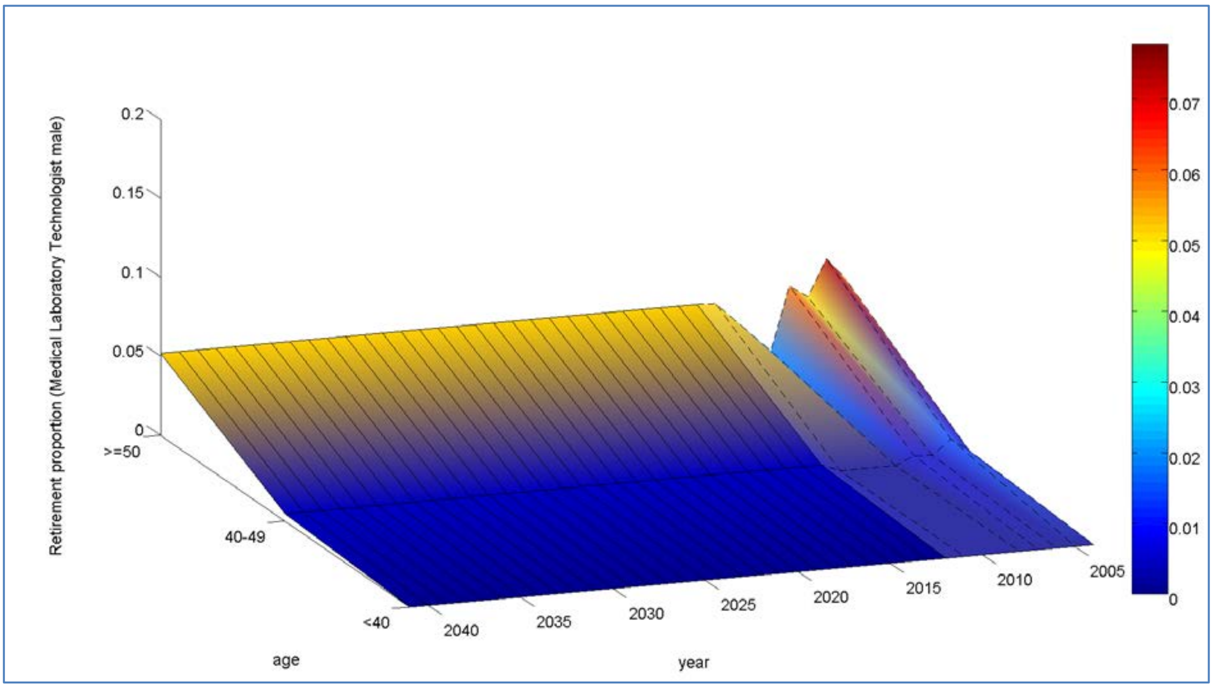

Figure 5.4(a) The proportion of MLTs 'Natural attrition/retirement' by age, male 2012-2041

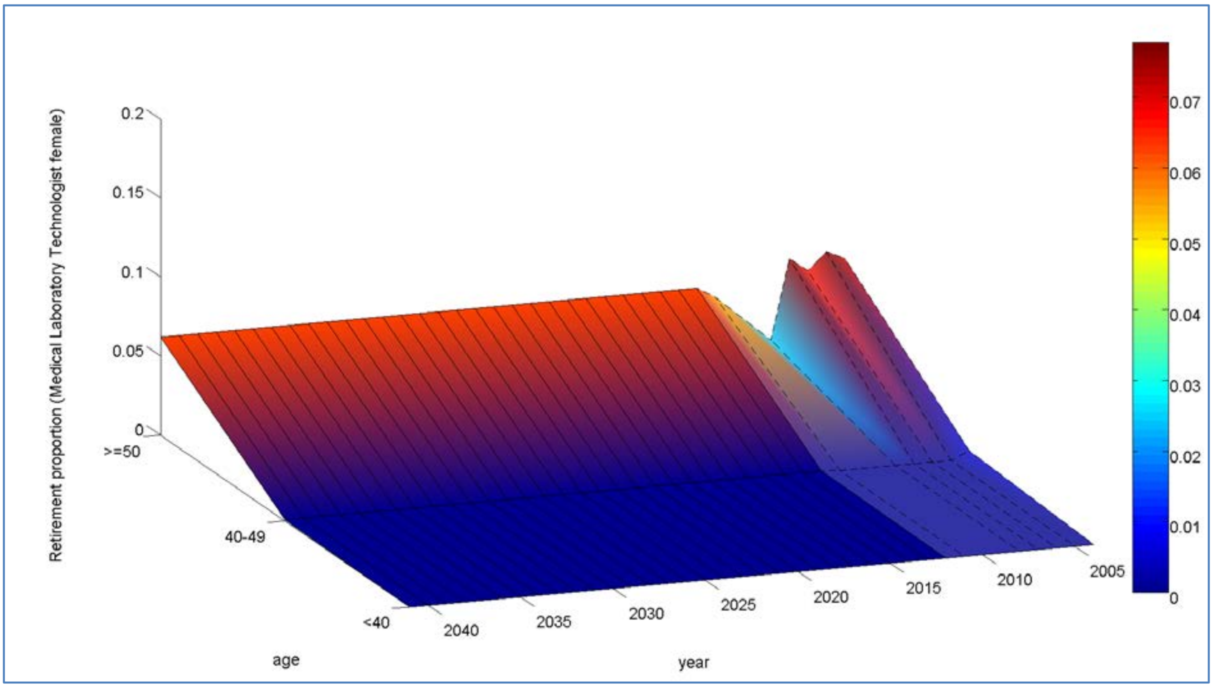

Figure 5.4(b) The proportion of MLTs 'Natural attrition/retirement' by age, female 2012-2041

5.2.2.3 Otherwise unavailable

"Otherwise unavailable" (those who have moved away from Hong Kong) MLTs are projected from the HMS on MLTs by sex and year (Figure 5.5). The five-year average proportion is applied to the projection.

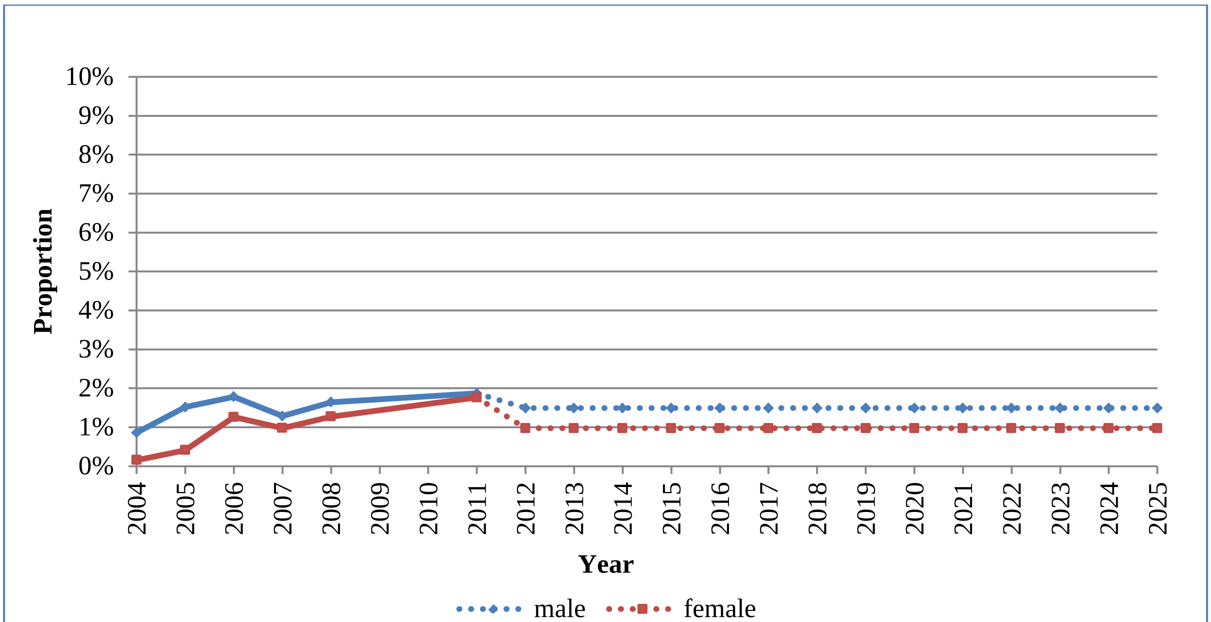

Figure 5.5 The proportion of MLTs 'otherwise unavailable' by sex (2012-2025)

5.3 Supply externalities

5.3.1 Workforce participation and differential work capacity

The supply model uses the HMS on MLTs to calculate the proportion of clinically active MLTs by service sectors (Hospital Authority, Other public [Government, Academic & Subvented], Private [medical and x-ray lab, medical clinic], and Private Institutions [private hospitals and other private institutions]) as each has different work patterns and female-male ratios (Figure 5.6). The supply model estimates the age-, sex-specific proportion of clinically active medical laboratory technologists by location and sector, differential work capacity, work pattern, and standard working hours.

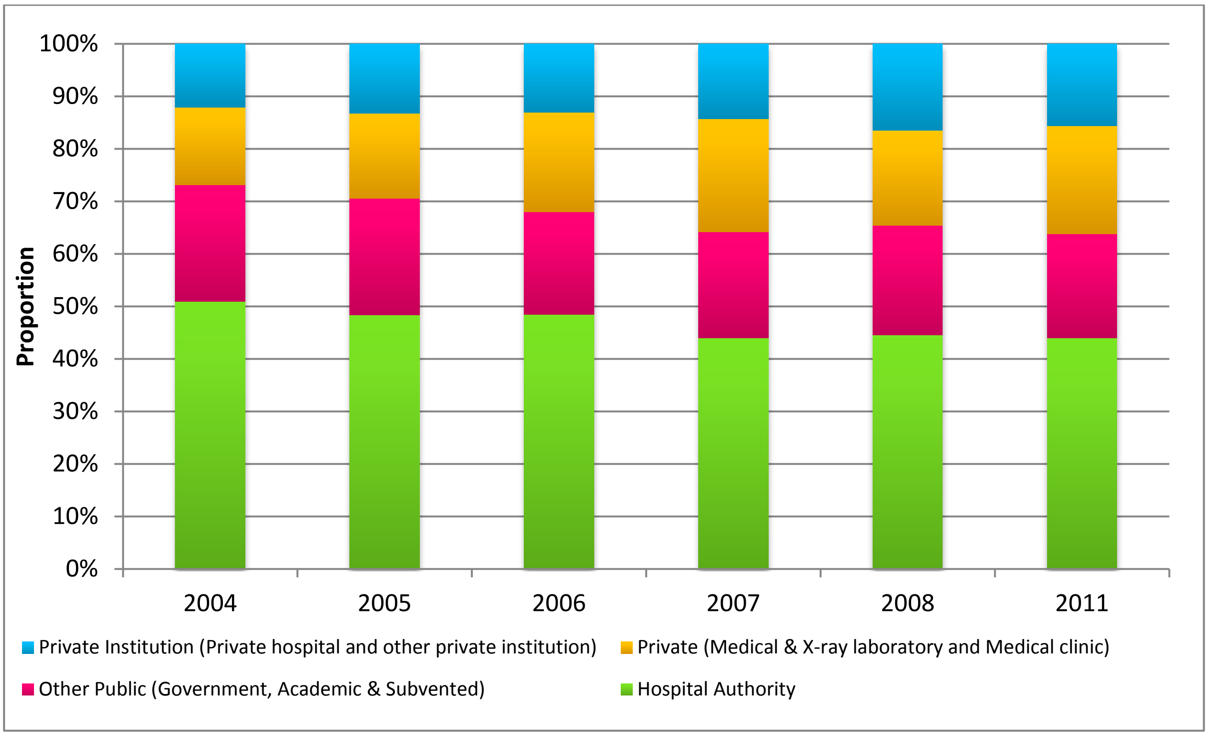

Figure 5.6 Proportion of MLTs by sector (HMS 2004-2008 & 2011)

5.4 Converting workforce supply to full time equivalents (FTEs)

The model uses the age-, sex-specific stratified average working hours to determine the total hours worked by sector. The average working hours in 'Hospital Authority', 'Other public' (Government, Academic & Subvented), private (medical and x-ray lab, medical clinic), and private Institutions (private hospitals and other private institutions)' is capped at 44 hours per week (equivalent to 1 FTE).

5.5 MLT supply projection from 2012-2041

5.5.1 Retirement scenarios

As expected, the projected retirement proportion increases by age, however, as the current population of MLTs are young, the projection is based on small numbers. Therefore three scenarios were used to observe variation in the supply projection based on different retirement assumptions for the ">=65" age group (Table 5.1).

Table 5.1Three scenarios of retirement assumptions for the ">=65" age group

Scenario	Retirement assumptions for the ">=65" age group
1	"Natural attrition/retirement" for ">=65" age group is assumed to be 100%
2	The average proportion of "Natural attrition/retirement" based on the HMS 2004-2007&2009 assumes all MLTs retire by 70 years of age
3	The average proportion of "Natural attrition/retirement" based on the HMS 2004-2007&2009 assumes all MLTs retire by 75 years of age

5.5.2 MLT supply projection

Table 4.2 presents the detailed projection outcomes for each of the variables in the supply model and the total FTE supply projection from 2015-2040 based on Scenario 1.

Table 5.2 Supply projection for MLTs (Scenario 1[1])

Year	2012[2]	2015	2020	2025	2030	2035	2040
Registrants							
Pre-existing registrants[3]	2896	3114	3327	3637	3847	4102	4266
Number of registrants after renewal[4]	2838	3053	3264	3569	3786	4039	4239
Graduate							
Local[5]	129	46	126	54	126	54	126
Non-local[6]	41	34	34	34	34	34	34
Newly eligible registrants	170	80	160	88	160	88	160
Total number of registrants	3008	3133	3424	3657	3946	4126	4400
Clinically inactive/unavailable[7]							
No longer practising in the medical laboratory profession but not retired	221	230	250	266	281	283	273
Natural attrition/retirement	16	33	44	81	170	297	573
Otherwise unavailable	36	37	40	42	45	44	42
Otherwise deregistered[8]	1	1	1	1	1	1	1
Number of inactive registrants[9]	277	302	352	414	537	721	1110
Number of clinically active/available registrants[10]	2731	2831	3071	3243	3408	3405	3289
Total FTE[11]	2719	2818	3058	3225	3384	3367	3255

1. In scenario 1, the average proportion of "Natural attrition/retirement" based on the HMS 2004-2008&2011[2] is used in the projection, and assumes all MLTs have retired by the age of 65
2. Base year from the Council Data (Adjusted for total number at December 2012)
3. Number of pre-existing registrants does not necessarily equal to the total number of registrants in the previous year, because the model exclude the registrants aged over 95.
4. The renewal rate; the number of registrants after renewal are derived from DH HMS for MLT (2004-2008 and 2011) .
5. The numbers of local graduates from local universities (PolyU, HKUSPACE); number of expected graduates held constant from 2018.
6. The numbers of non-local graduates from the Council; number of expected graduates held constant from 2018.
7. Proportion of clinically inactive/unavailable MLTs from DH HMS for MLT (2004-2008 and 2011), the average of the five years is applied to the projection
8. Assumed 1 permanent MLT deregistration per year
9. The total number of clinically inactive/unavailable MLTs is calculated by summing up the number of MLT in the categories of “No longer practicing in profession but not retired”, “Natural attrition/retirement”, “Otherwise unavailable” and “Otherwise deregistered”.
10. Total number of clinically active/available registrants
11. Total projected FTE

6 Gap analysis

The gap analysis quantified the difference between the projected demand for and supply of medical laboratory technologists for the base case (assumed demand and supply was at equilibrium from 2005 - 2011).

For the supply base case, the projected medical laboratory technologist FTE supply for the HA, the DH and the private sector.

6.1 Method

Three methods (annual number of FTEs, year-on-year FTE, and the annual incremental FTE) were used to quantify FTE medical laboratory technologist demand and compared to the base case supply projections for Hong Kong.

6.2 Annual number of FTE

The number of FTE medical laboratory technologist (by SVM) required in year y was as a function of the various utilisation measures in year y as described in the previous sections where :-

$$\text{Number of FTE } (y) = \sum_{i} n_{(i)}(y)c_{(i)}$$

$n_{(i)}(y)$ was the projected utilisation measure i in year y, and the $c_{(i)}$ the estimated FTE: $n_{(i)}$ ratio.

6.3 Year-on-Year FTE

The year-on-year FTE method quantified the year-on-year difference between demand and supply as follows :-

$$a(y) = Demand(y) - Supply(y)$$

where $a(y)$ was the year-on-year FTE at year y, $Demand(y)$ was the FTE demand at year y, and $Supply(y)$ is the FTE supply at year y.

6.4 Annual incremental FTE

The annual incremental FTE method quantified the change in the demand supply gap from the previous year as follow :-

$$I(y) = a(y) - a(y-1)$$

where $I(y)$was the annual incremental FTE at year y, $a(y)$ was the year-on-year FTE at year y, and $a(y-1)$ is the year-on-year FTE from the previous year.

6.5 Base case scenario

For the base case scenario, the FTE demand supply gap analysis projects a surplus of medical laboratory technologists (Figure 6.1 - 6.3) is the short term and thereafter a shortfall. The on average year-on-year projected FTE shortfall at 2015, 2025 and 2040 of 13, 417 and 1316 respectively (on average annual incremental shortfall at 2015, 2025 and 2040 of 47, 37 and 65 respectively) (assuming retirement at 65 years of age) (Table 6.1 – 6.2).

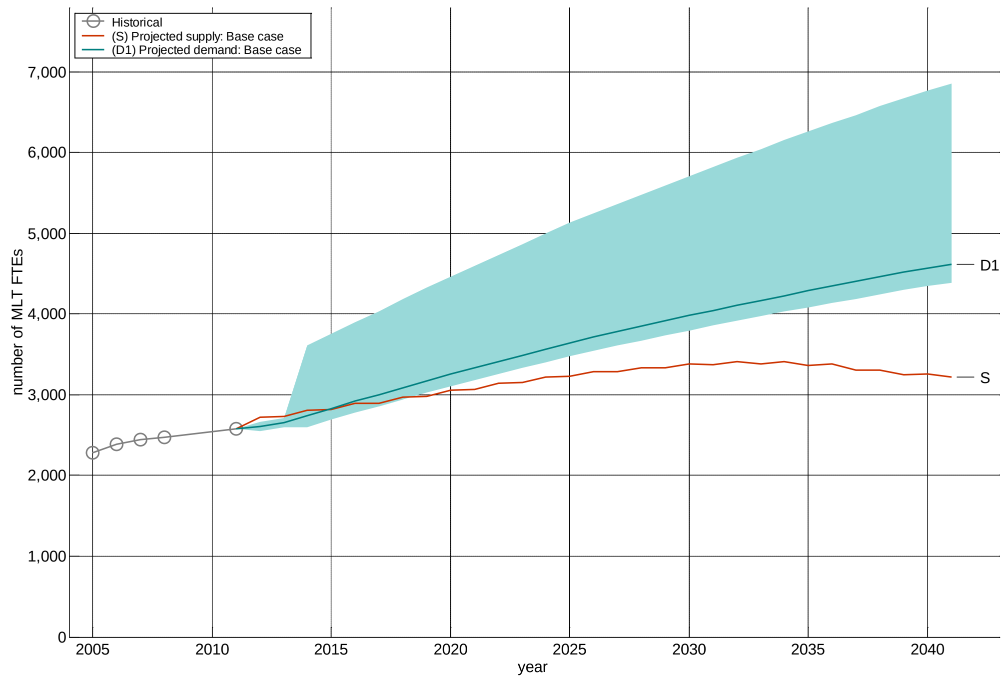

Figure 6.1 Historical and projected number of medical laboratory technologist FTEs: Base case supply and demand (Shaded area: 5th-95th percentile).

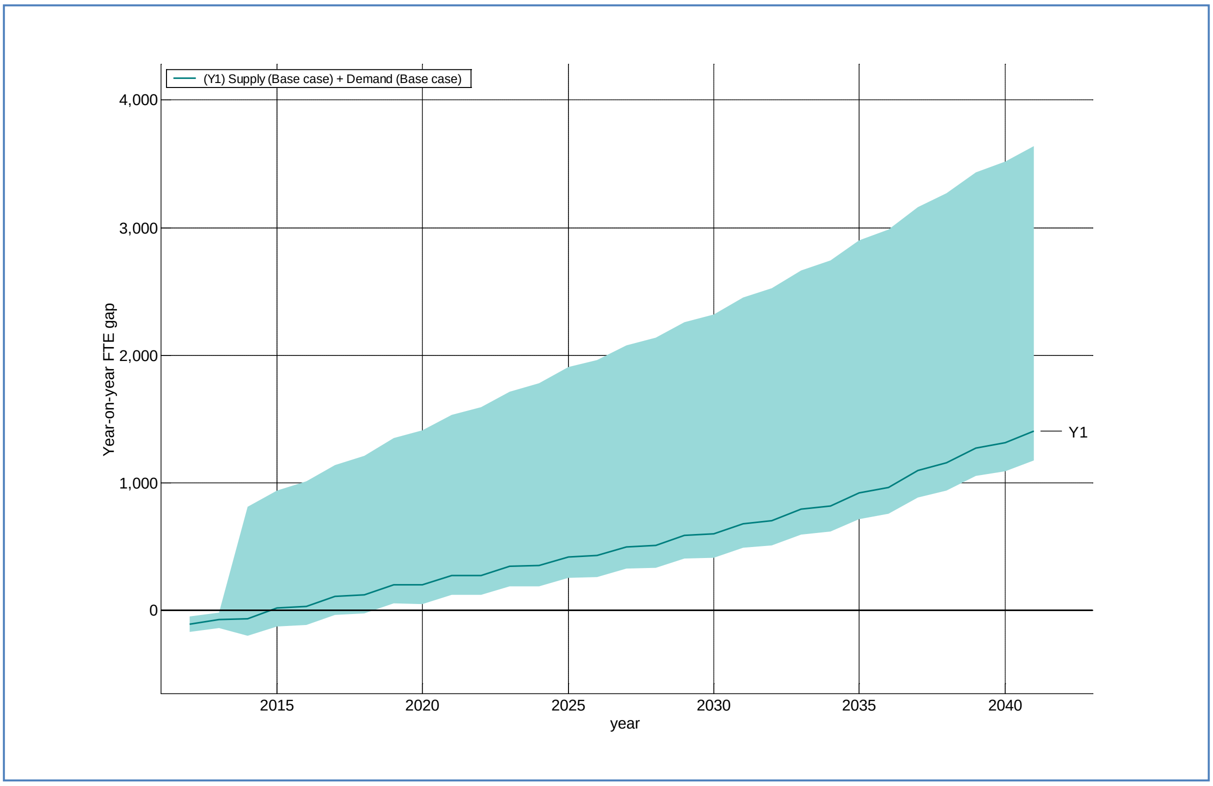

Figure 6.2 Year-on-year FTE gap: Base case demand model (Shaded area: 5th-95th percentile)

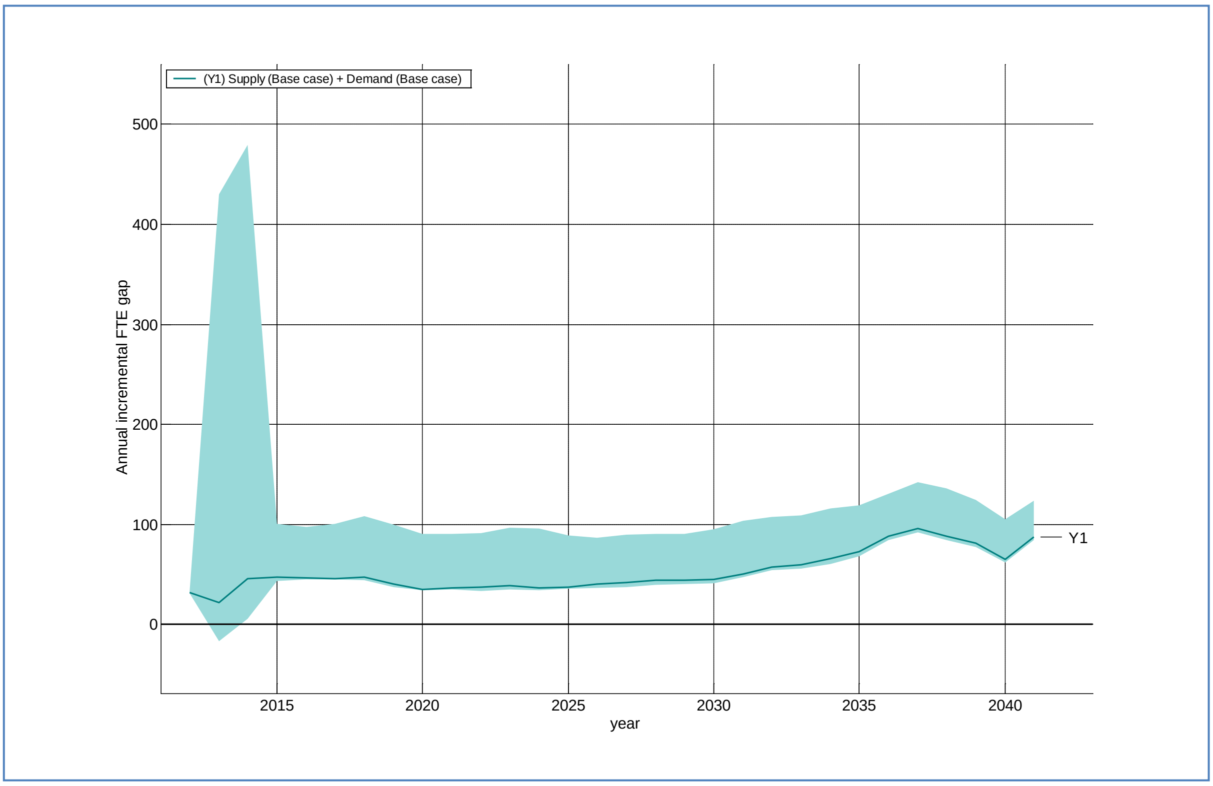

Figure 6.3 Annual incremental FTE gap: Base case demand model (Shaded area: 5th-95th percentile)

Table 6.1 Base case: projected year-on-year supply-demand gap [*a negative number indicates surplus]

	Best estimate	5th percentile	95th percentile
2015	13	-127	940
2020	200	48	1409
2025	417	252	1907
2030	598	413	2320
2035	921	715	2898
2040	1316	1091	3516

Table 6.2 Base case: projected annual incremental supply-demand gap [*a negative number indicates surplus]

	Best estimate	5th percentile	95th percentile
2015	47	1	47
2020	35	1	35
2025	37	1	37
2030	45	1	45
2035	73	1	73
2040	65	1	65

7 Comparison of 2012-2041 and 2015-2064 projections

The final model presents a comparison between two demand base case (based on the 2012-2041 and 2015-2064 CS&D demographic projections) FTE projections and the supply base case FTE projections as well as the year-on-year and annual incremental FTE gap (Figure 7.1 – 7.3, Tables 7.1 – 7.2). The 2015-2064 vs. 2012-2041 on average year-on-year FTE base case projections and the annual incremental supply-demand gap show a decrease in the MLT FTE shortfall from 2020.

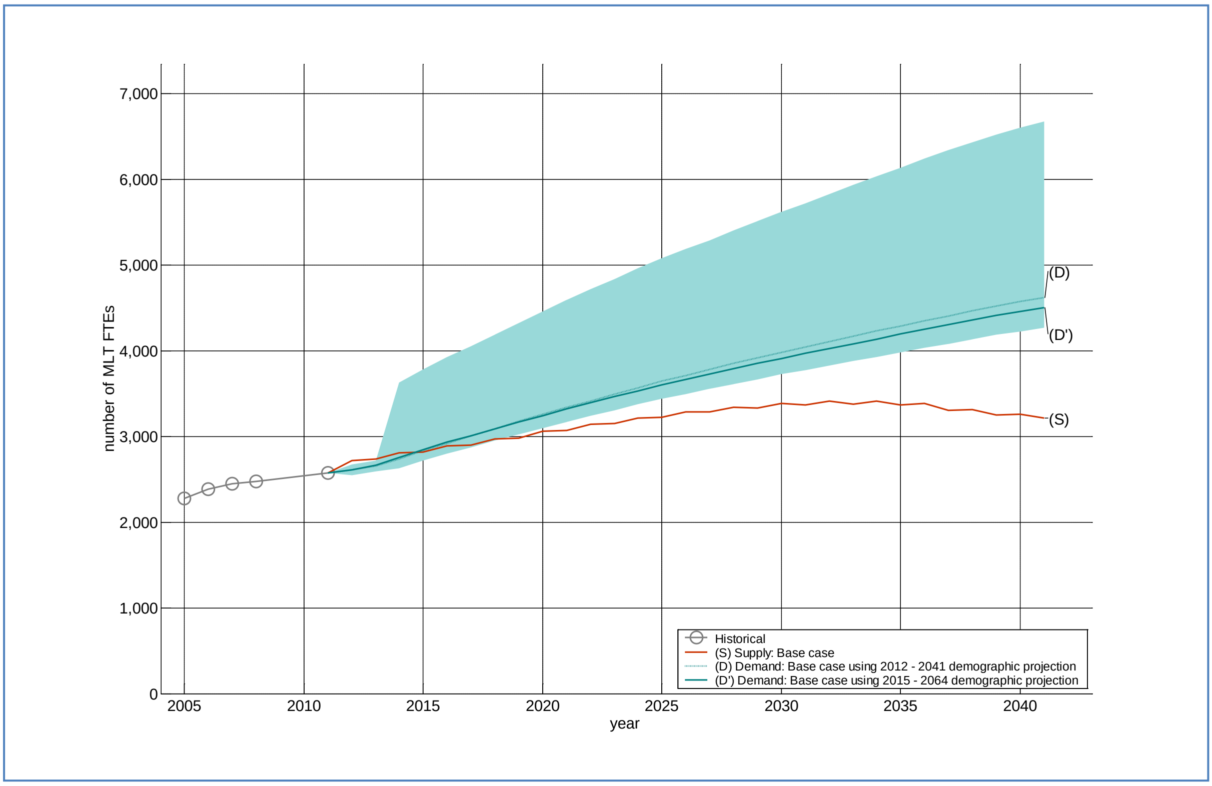

Figure 7.1 Historical and projected number of medical laboratory technologists FTEs: Base case supply and demand (Shaded area: 5th-95th percentile).

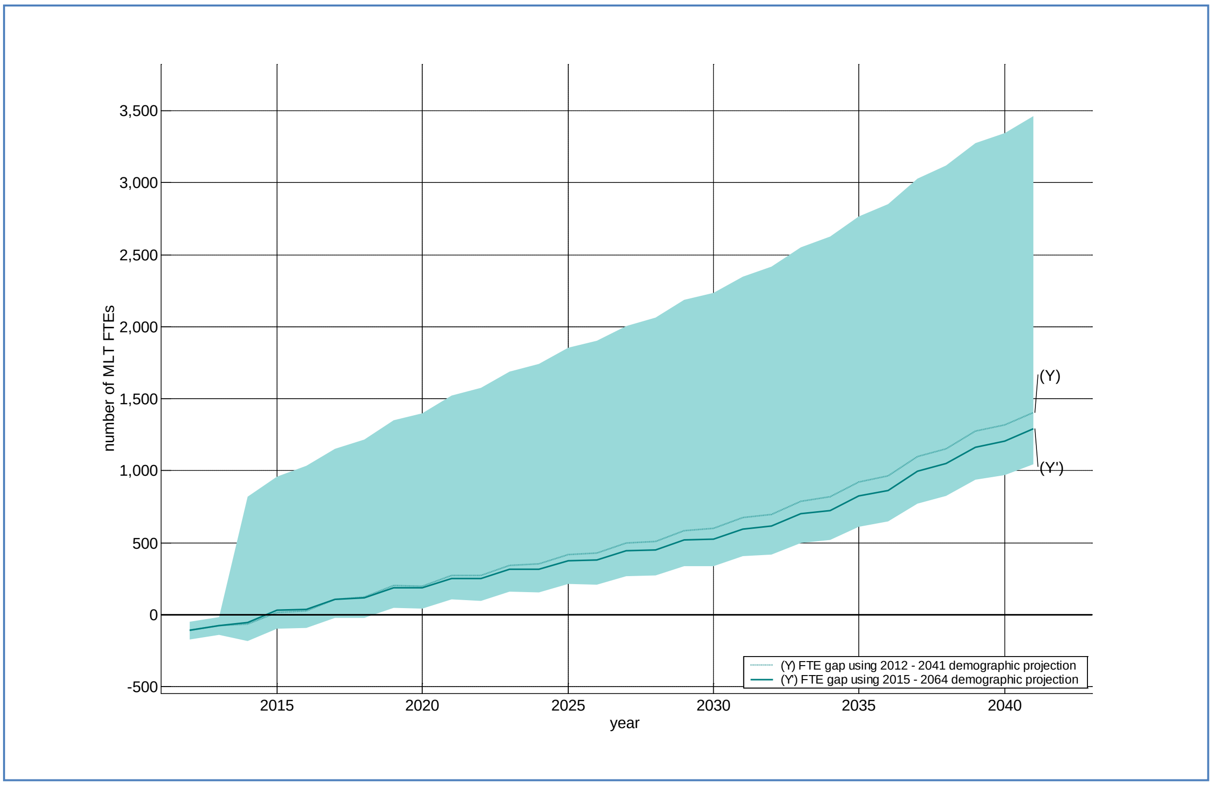

Figure 7.2 Year-on-year FTE gap: Base case demand model (Shaded area: 5th-95th percentile)

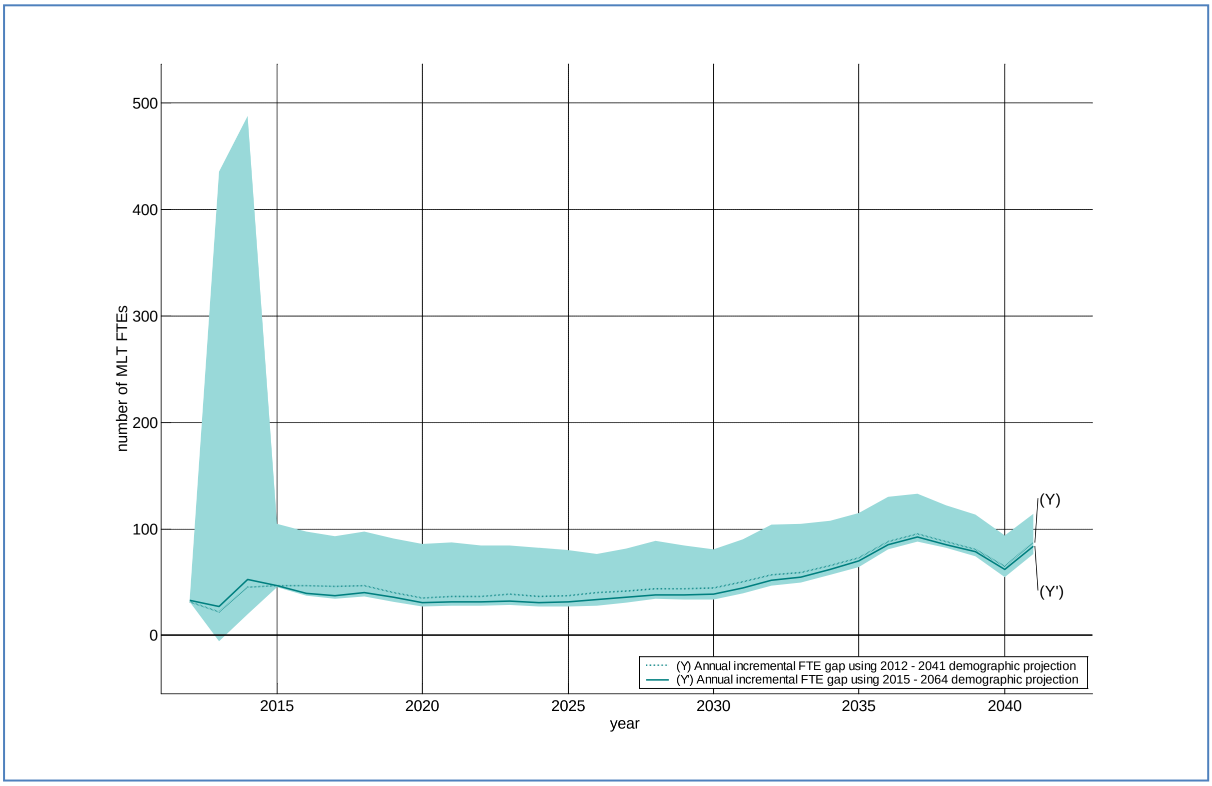

Figure 7.3 Annual incremental FTE gap: Base case demand model (Shaded area: 5th-95th percentile)

Table 7.1 Base case: projected year-on-year supply-demand gap (assuming retirement =>65 years of age) [*a negative number indicates surplus]

	Best estimate (2012-2041 demographic projection)	5th percentile	95th percentile	Best estimate (2015-2064 demographic projection)	5th percentile	95th percentile
2015	13	-127	940	29	-100	959
2020	200	48	1409	185	42	1400
2025	417	252	1907	375	213	1853
2030	598	413	2320	525	338	2234
2035	921	715	2898	825	612	2769
2040	1316	1091	3516	1205	971	3348

Table 7.2 Base case: projected annual incremental supply-demand gap (assuming retirement =>65 years of age) [*a negative number indicates surplus]

	Best estimate (2012-2041 demographic projection)	5th percentile	95th percentile	Best estimate (2015-2064 demographic projection)	5th percentile	95th percentile
2015	47	1	47	47	45	105
2020	35	1	35	31	27	86
2025	37	1	37	32	27	80
2030	45	1	45	39	34	81
2035	73	1	73	70	65	115
2040	65	1	65	62	55	94

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Appendix A(i): Summary of manpower planning and forecasting models (Australia, Canada, Netherlands)

	Australia	**Canada**	**Netherland**
Context	- shorter working hours for all healthcare professionals - ageing population - increasing demand for services - workforce distribution -	- utilisation-based planning failed to inform long-term workforce planning - planning has been done in isolation which resulted in unintended impacts, mismatch between need, supply and demand; - costly duplication, and inability to respond effectively to international issues/pressure	- shortage of medical specialist and nursing personal - steady growth in the healthcare workforce - increased feminization of the workforce and contracted GPs - impact of migration on health manpower planning
Objectives/ Strategic Directions	- ensure and sustain supply - optimise workforce and healthcare access - improve the healthcare work environment - enhance and coordinate health, education, vocational training and regulatory sectors - optimise use of workforce skills and ensure the best health outcomes - improve policy and planning to support the provision of staff - improve collaborative effort between all stakeholders	- increase the number of qualified healthcare trainees - focus on productivity and effective use of skills - improve access to healthcare services, address inappropriate variation of health human resources - create healthy, safe, supportive and learning workplace - maintain an skilled, experienced and dedicated workforce - more effective manpower planning and forecasting	- increase professional training - increase recruitment both to encourage staff to return to healthcare workforce and to recruit from overseas - retain staff by increasing support for staff and flexible working arrangements - change skill-mix
Framework	- align education and training supply with workforce requirements - improve workforce re-entry and ethical overseas recruitment - support work culture and develop flexible working environments - promote skills and competence initiatives - establish shared health workforce planning, research, information sharing, improve data collection - establish monitoring, evaluation and reporting processes - promote discussion and awareness amongst the stakeholders and community	- assess population health needs, demand for services including Aboriginal health needs - develop, implement and evaluate population need-based innovative service delivery and health human resource models - enhance collaboration and provide evidence for HHR planning information - align education curricula with health system needs and health policy - provide opportunities for to life-long learning - develop a locally, culturally and linguistically diverse workforce; - accelerate and expand the assessment and integration of internationally educated health professionals; - enhance healthcare career attractiveness - address health and safety issues, reduce work-related illnesses, injuries, and absenteeism	- increase collaboration between local and international institution in medical training programmes - increase training capacity, staff retention and recruitment - recruit healthcare professionals from within and outside EU - develop flexible and family-friendly working patterns - adjust the workloads for the older staff, and retirement age - provide learning and development opportunities - improve skill mix use and transfer of function between different professional groups - develop new roles and extend the range of work
Duration	since 2004 (reviewed in 2011)	since 2005	Since 2000s

	Australia	Canada	Netherland
Method for supply/ demand	**Supply and need-based model** **Demand** - utilisation of health services **Supply** - number of hours worked per year by the number of male and female health professionals in each age group - proportion of leavers and entries (graduates and migrants) into the health professional field	Collaborative system design and population health **need-based approach** to planning **Supply:** - actual number, type and geographical distribution of regulated and unregulated providers; productivity and scope of practice/service provided - labour market indicators: participation rate, provider-to-population ratios, demographic and educational characteristics of providers, employment status and sectors - death, retirement, emigration, replacement, general economic trends, work incentives, life-style choices. **Demand:** - population health needs for both curative and preventive health services	**The Dutch Simulation and Forecasting Model (supply-based)** confronted with 4 scenarios: - Scenario 0: unfulfilled demand for care + demographical developments - Scenario 1: Scenario 0 + non-demographical developments - Scenario 2: Scenario 1 + developments in working hour - Scenario 3: Scenario 2 + vertical substitution **The Dutch Policy and Planning Model** - a multi-stakeholder and multi-process consensus model - based on simulation model that generates GP training inflow advice yearly, allocation of funding and resources, and unplanned external factors to project GP workforce in coming years
Assumptions	**Demand** - time required for treating different conditions is binary - linear growth in demand. - demand model ignores labour substitution **Supply** - no change in technology - workforce entrance and exits, hours worked are disaggregated by age and sex groups. **General** - no interactions between the supply and demand models - no supplier-induced demand	- current supply of providers meet the current demand - observed trends are used to project future population size and demographic profile - future age and sex-specific resources remain constant	- historical trend continues - other projection of population growth, political and technical changes is on the right direction

	Australia	Canada	Netherland
Formulae	**Demand** $D_t = \beta_{st}activitysimple_t + \beta_{ct}activitycomplex_t$ D_t: Demand at a specific time *activitysimple*: simple utilisation *activitycomplex*: complex utilisation Each activity has a coefficient β_{st} and β_{ct} with $\beta_{st} < \beta_{ct}$ relating activity into demand for full-time equivalent health professional hours at time *t*, D_t. **Supply** $S_t = \Sigma_g[\beta_{g,male}male_{tg} + \beta_{g,female}female_{tg}]male_{tg} = (1-\beta^{loss}_{g,male}) male_{t-1g} + malegrads_{tg} + malemigrants_{tg}female_{tg} = (1-\beta^{loss}_{g,female}) female_{t-1g} + femalegrads_{tg} + femalemigrants_{tg}$ S_t: supply of labour hours in year *tg*: age groups $\beta_{g,male}$ and $\beta_{g,female}$: coefficients that represent the number of hours worked $\beta^{loss}_{g,male}$ and $\beta^{loss}_{g,female}$: proportion of the workforce loss every year $malegrads_{tg}$ and $femalegrads_{tg}$: number of graduates $malemigrants_{tg}$ and $femalemigrants_{tg}$: number of migrants	Modelling utilisation and predicted used based on needs $y_i = \sum_{j=1}^{J} \beta_j A_{ij} + \sum_{k=1}^{K} \lambda_k X_{ik} + \sum_{j=1}^{J} \sum_{k=1}^{K} \delta_{jk} A_{ij} X_{ik} + \sum_{l=1}^{L} \gamma_l Z_{il} + \sum_{m=1}^{M} \varphi_m R_{im} + \varepsilon_i$ Allocation of resources: $N_r = \sum_I {}_r w_i \hat{y}_i^+ \Big/ \sum_I {}_r w_i$ y_i: utilisation for individual i; A_{ij}: vector of age-sex dummies X_{ik}: vector of additional needs indicators Z_{il}: vector of non-need determinants of utilisation R_{im}: dummy variables for regions *β, λ, γ, δ, ø* estimated coefficient vectors N_r: per capita resource need for residents of each allocation regionw: the survey sample weight for each individual i w_i: survey sample weight for individual	- Required supply in year T vs. Required supply in year X => development required supply until T+X - Available supply in year T + Development available supply until T+X => Available supply in year T+X

	Australia	Canada	Netherland
Key factors used	- numbers in the workforce in a given year (by age and sex) - proportion of individuals leaving workforce by sex - number of graduates and migrants - utilisation of healthcare services	- actual and perceived population health status, socio-economic status - demographics - health behaviours - social, cultural, political, contextual, geographical, environmental - financial factors - categories/roles/characteristics of health workers and services, source of supply - production (education + training): target vs. actual needs projected - management, organization and delivery of health services (indirectly contribute to outcomes), formalization/centralization, environmental complexity, amount and quality of care provided, costs associated with delivery of services and outcomes - resource deployment and utilisation - health outcomes: e.g. mortality data, hospital discharge, life expectancy, and disease incidence. (depends on community's situation)	- available supply of GPs (total full-time equivalent) - unfulfilled demand for care - number of GP in training - inflow from abroad - outflow (male/female & projection year) - return on training - labour market return - epidemiological developments - socio-cultural developments - technical developments - substitution
Limitations/ Challenges	**Demand** - binary case-mix - linear demand growth - constant returns - no labour substitution **Supply** - no changes in technology - disaggregated by age and sex **General** - independent supply and demand - no supplier-induced demand	- require extensive data => difficulties in management and maintenance of data collection, delivery system - lack of consistent information on health human resource productivity, workload, utilisation demand and efficacy; and information about educational facilities - capacity to assess health needs, and forecast demand for health human resources- funding for ongoing data and modelling initiatives - compliance vs. flexibility and autonomy of local/regional planner with national strategies - updating model is difficult - the model is more likely to project unattainable service and staff targets	- technically complex: many parameters, heuristics, sub-models and data source - politically complex: multiple policy discussions and stakeholder involvement - intentionally complex: long-term planning, short-term acting, frequent updating
Organisation	National Health Workforce Taskforce Australian Health Ministries' Advisory Council (http://www.ahwo.gov.au/index.asp)	www.hc-sc.gc.ca (Health Canada)	NIVEL (the Netherlands Institute for Health Services Research) http://www.nivel.nl/ Dutch Ministry of Health, Welfare and Sport Dutch Health professional organizations and labour unions

Appendix A(ii): Summary of manpower planning and forecasting models (New Zealand, Scotland, United Kingdom)

	New Zealand	Scotland	United Kingdom
Context	- increasing burden of chronic diseases - lack of collaboration in planning and implementation of health workforce - mental health, rehabilitation and aged care are an emerging a problem	- increase the size of healthcare workforce - aging healthcare workforce - workforce is predominately female and predominately working fulltime	A number of changes in the UK population, service delivery model, and healthcare workforce - demographic - a growing, aging population - NHS funding and budgets - service plans and reconfiguration - policy (locus of care from hospital to community, from NHS to non-NHS) - legislative and regulatory framework - professional education - role definition for each of the professions
Objectives/ Strategic directions	- innovative approaches to workforce development - enhance communication - sector relationships - build a responsible and rational workforce development investment plan (set workforce development priority for mental health, rehabilitation and aged care) - support the healthcare workforce boards and policy makers	- develop and implement multi-disciplinary and multi-agency models of care which are more responsive, accessible and joined up to meet the needs of local communities and ensure efficient utilisation of skills and resources - motivate employees to improve their performance, provide opportunities for them to develop and contribute more - promote the benefits of preventative action and measures of self-care for patients and public across a range of health issues - maximise and wider access to education and training, especially for those at underserved areas	- engage with health sector employers to ensure the authoritative sector voice on skills and workforce development for the whole sector - inform the development and application of workforce policy through research and the provision of robust labour market intelligence - implement solutions which deliver a skilled, flexible and modernised workforce capable of improving productivity, performance and reducing health inequalities - champion an approach to workforce planning and development that is based on the common currency of national workforce competences.
Framework	- increase number of healthcare professionals - train and recruit more health professionals with generic skills, to increase flexibility and respond to the increasing shift towards primary and community-based models of care and integration between institutional and community settings - improve workforce activity linkages in health system, collaboration and economies of scales - develop regionally aligned approaches to professional training and career planning - enable health professionals to take on new tasks, responsibilities, opportunities for further development, and career satisfaction.	- partnership with professional groups to support delivery and development of services - support professional groups to achieve their full personal and professional potential - funding arrangement for professional development and continuing education - encourage sharing between professional groups, and learning from each others across national, regional sectors - provide guideline for better care delivery models, encourage innovative approaches - fund professional development courses - develop better evidence base to inform policies and strategies to help promote retention of staff	- develop workforce plans and strategies for investment - commission undergraduate training and clinical placements - manage post registration and post graduate training - invest in continuing professional development - train and develop wider healthcare workforce esp. nurse and other ancillary team - allocate and monitor investment of education and training funds - collaborate at all levels of the system to plan and develop the workforce for quality
Duration	HWAC: since 2000 HWNZ: since 2009	since 2000s	since 2000s

	New Zealand	Scotland	United Kingdom
Method for supply/ demand	Primary Healthcare Nursing projection modelling **(demand-based)** **Supply:** - projected proportion and distribution of healthcare professionals by age, sex, geographic - entrants to and graduates from education and training programme - retirement, mortality, career change, disability of healthcare workforce **Demand:** - population growth projections by age, gender and ethnicity - population health needs - historical, current, and future changes of services provided - anticipated development of and changes in-patient care practice - impact of current and emerging technologies	**Demand and supply-based plan** **Demand:** - rate of general practitioners - patients contact by sex and age (estimated by changes of characteristics of population) - working time targets and standards and real practice - working time regulations - service utilisation - service levels **Supply:** - destination of GP registrants (age profile; gender profile) - growth of GPs training	No single model/method used, but various in term of regional and local level Example: **England:** - NHS Workforce Review Team: conduct a pilot study to develop demand-side modelling (initially for mental health service) (England) - London Strategic Health Authority: used scenario-based workforce modelling (demand-based) - 6-step Workforce Planning Model (NHS South West) (supply and demand) **Northern Ireland:** - review of each professional group every three years, plan/strategies were made based on supply and demand **Scotland:** - based on Student Nurse Intake Planning project aligned with NHS and non-NHS employers projection (supply) - utilisation of service from Management Information and Dental Accounting System database (demand) **Wales:** - annual approach will be based on national unit linked to local planning process (supply)
Assumptions	- past trends define future trends - demand will increase at twice the rate of population growth	- estimated numbers based on average calculation of past trend and prediction of change of care delivery models, technology - significant work has been undertaken to ensure that workforce targets are consistent with the available resources	- each model applied holds different assumptions
Formulae	**Supply** = Headcounts + net inflow (inflow less outflow) (calculated for each workforce areas) **Demand** = [population growth] * [type of service] * [care delivery models] * [impact of current and future technologies]	Projected demand (Whole time equivalent) = current demand * yearly growth rate Required supply = estimated adequate ratio of supply to demand * projected demand	Supply=current headcounts + net inflow; Demand = population * dentist-to-population ratio,

	New Zealand	Scotland	United Kingdom
Key factors used	- projection of population growth by age, sex - population health needs: based on all types of healthcare services - burden of disease - technology development - models of care - projection of healthcare workforce growth according to population growth - entries to and exits from healthcare workforce - analysis of occupations, specialty - education and training sources	- workforce dynamics (characteristics of workforce development) - demographic changes - technology development - payment scheme - utilisation (service-based) - shrinkage (leave, mortality, retirement)	Depends on model used Example: - number of student intake for a professional training retirement, change of professions, expansion - financial planning for education and training - international recruitment - health indicators, demographic and socio-economic status
Limitations/ Challenges	- difficult to collect and monitor data - lack of financial support in services at rural areas, and which make coordination between care centres difficult. - difficult to evaluate impact of policy changes and health outcomes	- relies on pre and current data - quality of data is an issue - lack of collaborative approaches to workforce planning	- lack of supply-side modelling - lack of linkage between supply and demand projections - potential deficit in current workforce-planning capacity at regional level - most Strategic Health Authorities focused on improving the process, rather than planning capacity **Problems in the system:** - too "top-down" management- service, financial and workforce planning are poorly integrated - poor data to project funding arrangement - medical workforce planning and development is done largely in isolation - lack of long-term strategic commission - quality of education, training, recruitment
Organizations	Health Workforce Advisory Committee (HWAC) http://www.healthworkforce.govt.nz/about-health-workforce-nz/publications-and-reports Workforce Services Reviews	NHS Scotland National Workforce Planning	Department of Health Centre for Workforce Intelligence (http://www.cfwi.org.uk/) Skills for Health

Appendix A(iii): Summary of manpower planning and forecasting models (Japan, Singapore, USA)

	Japan	Singapore	USA
Context	- shortage of physicians - mal-distribution of medical practitioners in some areas - ageing population - ageing workforce - mismatch of supply-demand in some areas	- high density of doctors, but reported shortages in the public sector due to the low pay and long working hours compared with the private sector - promote medical tourism - import medical workforce, esp. nurses and doctors from Philippine and Indonesia - most of doctors in Singapore are foreign-trained	- shortage in primary care service and staff - nursing shortage - geographical variation in service - inappropriate funding plan - increased demand professional training program
Objectives/ Strategic directions	- to project the demand and supply of healthcare professionals	- increase medical and other healthcare professional training - improve working environment and benefits to attract more overseas healthcare workers - develop programmes to recruit and retain healthcare workforce (esp. professional Development)	- strengthen the Nation's Health and Human Services Infrastructure and workforce - invest in the HHS workforce to meet American's health and human service needs today and tomorrow - ensure that the Nation's healthcare workforce can meet increased demands - enhance the ability of the public health workforce to improve public health at home and abroad - strengthen the Nation's human service workforce
Framework	- train and recruit more health professionals to respond to the increasing shift towards elderly care and integration between institutional and community settings - enable health professionals to take on new tasks, responsibilities, opportunities	- Healthcare Manpower Development Programme for Intermediate and Long-term Care (since 1980) - funding for advanced training skill of local staff (local or overseas institution) - funding for visiting experts' lecture, fellowship programme - set up websites to attract more foreign healthcare workers	- fund medical training scholarships and loan repayment programmes - focus on human capital development - innovative approaches to recruiting, training, develop, retain and support a competent workforce - monitor and assess the adequacy of the Nation's health professions workforce - work with states to develop systems for the training and ongoing professional development, and opportunities for developing professional skills. - improve the cultural competence of the healthcare workforce - foster the use of evidence-based practices in human services to professionalize the field - establish regular evaluation, supervision of supply and demand of healthcare workforce to inform professional development and future action.
Duration	since 2000	since 2006	since 2006

	Japan	Singapore	USA
Method for Supply/ Demand	**Utilisation and supply-based approach** - current and past trend of utilisation (esp. for aging care) - expenses related to healthcare - education and training sources - population development - advancing medical technology - changing treatment patterns - labour market trends	- healthcare professionals to population ratio * Doctors to population ratio: 1:620 (2008); 1:600 (2009); 1:580 (2010); 1:550 (2011) * Nurse to population ratio: 1:200 (2008); 1:190 (2009); 1:170 (2010); 1:160 (2011) - **supply-based model** was used to project healthcare workforce	**Utilisation and supply-based model** **Supply:** - size and characteristics of current workforce (age, gender, work-hours, retirement, distribution, active in-patient care or other activities such as teaching, research) - new entrants and choice of medical specialty - separation from the physician workforce (retirement, mortality, disability, career change) - physicians productivity: hours spent providing patient care, number of patients seen, resource-based relative value scale **Demand:** - population growth - medical insurance trends - economic factors - physician to population ratio - technology, policy changes
Assumptions	- population projections, current patterns of employment and supply - models used are susceptible to measurement error	- assumption: current patterns of new local and non-local graduates, - rates of demand will remain	- baseline assumption: current patterns of new graduates, specialty choice, and practice behaviour continue - distribution of physicians in-patient-care and other activities remains constant
Formulae	stock and flow methods	- The healthcare workforce (doctors, nurses, pharmacists, dentists and allied health professionals) will need to be increased by more than 50%, by 2020.. - Factors being considered include ageing and growing population, and increasing number of healthcare infrastructure. On the supply side, local and overseas graduates and role extension of healthcare professionals were considered.	**Physician Supply Model** $P_{(y+1)} = P_{(y)} + P_a - P_i + P_n$ P(y+1): physicians supply in the year y+1 P(y): physicians supply in the year yPa: physicians remain active Pi: physicians inactive, retired, dead or disable Pn: new physicians graduated from US medical school or international institutions The model also generates Full-time equivalent (FTE) physicians, which is defined as the average hour annual hours worked in-patient care per physician in baseline year. **Physician Requirement Model** - Physicians Requirements = [*Population projections by age, sex, and metro/non-metro*] x [*Insurance distribution by age, sex, and metro/non-metro*] x [*physicians per population ratio by age, sex, and metro/non-metro, insurance and specialty*]

	Japan	**Singapore**	**USA**
Key factors used	- population growth rate - healthcare workers to population ratio - utilisation indicators	- number of physicians/nurses - inflow and outflow of healthcare workforce - population growth rate - medical education and training registrants	**Physician Supply Model** - number of physicians in the preceding years (starting with the base year 2000) - number of new US medical students, International medical students - attrition due to retirement, death and disability **Physician Requirement Model** - population projections by age, sex and metropolitan/non-metropolitan location - projected insurance distribution by insurance type, age, sex, metropolitan/non-metropolitan location - detailed physician-to-population ratio
Limitations/ Challenges	- slow adoption of new approaches across healthcare systems - loose control over supply and demand factors due to no central authority - difficulty in funding allocation	- past history may not adequately reflect future requirements - limited variables include in the analysis - overly reliant on ability to recruit non-local professionals	- numerous variables included in the analysis => difficult to control => uncertainty about adequacy of the analysis - no single entity in US in charge of workforce planning- - lack a cohesive approach to workforce shortage
Organisation	Ministry of Health, Labour and Welfare Human Resource Development Bureau	Ministry of Health Human Resource Advisory Board	US Department of Health and Human Services (http://www.hrsa.gov/index.html) American Society for Healthcare Human Resources Administration (ASHHRA http://www.ashhra.org)

Appendix B: Manpower planning literature by healthcare professional group

Doctors

Author, year	Design, model type /analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Supply models				
Bane et al., 1959 (164)	Stock and flow approach.	Graduates; Number of physicians; Retirees; Work locations;	•Number of physicians per 100000 people •Total output	• Estimates of future needs were projected through analysing the utilisation of services, growth of new types of services.
Craig et al., 2002 (74)	Trend analysis.	Number of specialist anaesthesiologists by age, as of January 1, 2000; Annual certificate numbers, 1971-2000; Estimated needs for anesthesia provider, 1999 & 2006.	•Number of required FTEs •Number of FTE deficits	• Assumption that each anaesthesiologist provides 1 FTE to anaesthesiology workforce underestimates requirement.; • Does not account for anaesthetic service provided by non-specialist practitioners.
Fraher et al., 2013 (165)	Stock and flow approach.	Graduate medical education pipeline; Length of training by specialty; Re-entry; Attrition (Death, retirement and career breaks); Age; Sex; Hours worked in-patient care by age and sex.	•Headcount of surgeons by age, sex and specialty in the United States from 2009 to 2028 FTE of surgeons by age, sex and specialty in the United States from 2009 to 2028	• Does not cover the complementary of physician assistant and nurses; • FTE contributions to patient care were adjusted downward significantly after the age of 65 years; • FTE by age and sex, retirement rates, workforce re-entry patterns and attrition from training stay the same in different specialties; • Only focus on overall supply.

Author, year	Design, model type /analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Fehring et al., 2010 (71)	Stock and flow approach.	Age; Retirement; Graduates; Number of total knee and total hip arthroplasties performed per month; Historical incidence of arthroplasty.	•Procedural shortfall	• Selection and information bias through the use of estimates that are based on survey data; • Assumption of baseline scenario and conservative scenario for retirement; • Assumption of baseline scenario and conservative scenario for incidence; • The number of residents entering the workforce will be stable; • All the surgeons will perform joint arthroplasty at the same rate, no matter their experience.
Hilton et al., 1998 (75)	Stock and flow approach.	Number of current supply of physicians; Number of new trainees; Number of licensees expected; Retirement; Population; Number of office-based physicians; Hospital-based physicians; Specialties vs. primary care physicians; Other activities.	•Total number of office-based physicians per 100,000 population in 2001 & 2006 •The number of primary care physicians per 100,000 population in 2001 & 2006 •The number of specialist per 100,000 population in 2001 & 2006	• Limited effect of growth in demand on current number of physicians to 1%/year. • Limited retirement and other losses to 3%/year; Assume 70% retention rate of trainees; • 1.2% of population increase annually.
Joyce et al., 2006 (67)	Stock and flow approach.	Current supply in baseline; New graduates; Immigrants; Re-entrants; Death; Retirements; Attrition exits; Movement between occupations; Number of hours worked per week by age (5-year bands) and sex.	•FTE clinicians (per 100,000) •FTE GP (per 100,000) •FTE Specialist workforce (per 100,000)	• Estimate of parameters used in the model might not be accurate – question of data quality.

Author, year	Design, model type /analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Koike et al., 2009 (72)	Trend analysis using multistate life table.	Specialty; Impact of further increase of female physicians Age groups; Place of work.	•Headcount of estimated numbers of physicians by specialty	• The characteristics and status of physicians will continue in the future; • Does not project the FTE number.
Miller, 1993 (76)	Stock and flow approach.	Age distribution; Number of otolaryngologists; Number of otolaryngologists entering practice; Death rates; Retirements; Current production of residents.	•Headcount of otolaryngologists	• Older-than-65 group was excluded from further analysis.
Satiani et al., 2009 (73)	Stock and flow approach, using population and workload analysis.	Current number of certified Vascular surgeons; Number of newly certified per year; Retired numbers per year; Operations needed per 100000 people; Average number of procedures performed per VSN	•Population analysis: Shortage of surgeons in percentage •Workload analysis: Shortage of surgeons in percentage	• Surgeon to population ratio maintained for the 40-year period, number of operations performed annually remain the same, number of years in training remain unchanged.
Demand models				
Craig et al., 2002 (74)	Needs-based model.	Per capita utilisation by age and sex; Population projection by age and sex; Time spent on providing clinical anaesthesia services;	•FTE of physicians	• Lack of direct data on non-clinical anaesthesiologists; • Assume that one full-time, full-year anaesthesiologist equals to 175,000 units of demand; • Assume that the supply meets the demand in the base year.

Author, year	Design, model type /analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Etzioni et al., 2003 (11)	Demand/utilisation based model.	Population by age; Age-specific rates of surgical procedures; Relative value units (RVUs).	•Forecasted percept increases in Work RVUs by specialty	• Estimate workload/productivity; • Assume that the surgical demand by age and sex will be stable.
Greenberg et al, 1997 (166)	Demand/utilisation-based model.	Current utilisation rates for ambulatory and in-patient medical; Specialty services, by gender, race, age group, insurance status; Population by gender, race and age.	•Physician headcount required in 2020	• Recent trends will continue into the future.
Harrison et al., 2011 (167)	Demand/Utilisation-based model.	Number of general practice consultations by age and gender; Length consultations; Population projection.	•Increase in GP utilisation •Additional GPs required	• Assume that GPs would work similar average hours per week; • Assume that current primary care model and structure of general practice will remain the same.
Tsai et al., 2012 (168)	Regression-based physician density model.	Mortality rate (under age 5); Adult mortality rate; Life expectancy; Fertility rate; Literacy; Population density; Age structure; Economic growth; Expenditure on health.	•Under the model, countries were labelled as Negative discrepancy or Positive discrepancy	• Cannot use the absolute number to suggest for correction in the healthcare workforce; • Only be used for warning signs of workforce discrepancy
Mixed models				
Al-Jarallah et al., 2009 (169)	Supply: trend analysis; Demand: benchmark.	Population projections; Physician-to-population ratios; The average rate per annum for Kuwaiti physicians and non-Kuwaiti physicians.	•Number of indigenous physician and non-native expatriate physician •Projected requirement for physician •Disparity between need and actual number of physicians	• Projecting demand and supply over a long period leads to uncertainty, did not study age and structure of the physician workforce due the lack of data.

Author, year	**Design, model type /analysis**	**Parameters included** **(population level or individual level)**	**Outcomes**	**Assumptions & Limitations**
Barber et al., 2010 (69)	Supply: stock and flow approach; Demand: demand/utilization-based model.	Number of students admitted to medical school; Number of residencies available for each specialty; The mandatory retirement age; Immigration rate by specialty; Growth rate for specialists demand; Growth in population;	•Total FTE of medical specialists needed •Ratio specialists/100 000 inhabitants •Deficit/surplus specialists in percent	• Supply model: realistic entry parameters; • Demand model: lack normative standards, assume appropriate staff number.
Birch et al., 2007 (170)	Supply: stock and flow approach; Demand: needs-based framework using Vensim 2002 simulation model.	Number of provider by age and sex; Time spent in the production of services; Size of population by age and sex; Provider-to-population ratio by age and sex of population group; Number of services required by age and sex; Demography; Level of service; Epidemiology; Intensity of work; Technological inputs; Inputs of other types of professionals.	•Headcount of the providers •FTE of the providers •Need follows observed trends by different policy changes	• Assumption of different needs scenarios to look at how it will affect the physician workforce.

Author, year	Design, model type /analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Blinman et al., 2012 (171)	Supply: stock and flow approach; Demand: demand-based model.	Headcount by nature of practice; Current supply; Population; National chemotherapy utilisation rate; Optimal workload of new patients seen per FTE MO per year; Number of retirement; Overseas and local training MOs.	•Supply, demand and shortfall of FTE medical oncologists (MOs) •Chemotherapy utilisation rate	• Only the clinical workload of MOs related to chemotherapy was included, some responses were estimated than counted, lead clinicians were surveyed rather than individual MOs.
Chang et al., 2008 (68)	Supply: stock and flow approach; Demand: needs-based model.	Number of new entrants; Current manpower and demographics; Withdrawals by nephrologists (e.g. retirement, death and turnover to other subspecialties); Population; Incidence and prevalence of ESRD and treatment modalities.	•FTE supply, demand	• Assume the probability of wastage for general doctors and internists are small and therefore ignored.
Cooper 1995 (172)	Supply: dynamic model; Demand: demand/utilisation-based model.	Medical students; Retirement; Size of workforce; Utilisation from HMOs; Aging; Technology; Productivity; Demographic factors; Population.	•FTE physician/100000 population (supply and demand)	• Supply: limited by predictions concerning the future number of USMGs and IMGs; • Demand: uncertainty of technology, data reliability from HMOs, HMOs' data not representative of the nation as a whole.
Deal et al., 2007 (173)	Supply: stock and flow approach; Demand: demand/utilisation-based model.	Healthcare utilisation - age & sex; Population projections; Retirement; Mortality rates; Hours of work; Number and fill rates of fellowship slots.	•Number of rheumatologists supplied and needed, by sex, age and specialty	• Supply and demand for rheumatology services are in equilibrium, the number of fellow position will remain static, gender differences will remain static.

Author, year	Design, model type /analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Douglass et al., 1995 (174)	Supply: dynamic model; Demand: needs-based model.	Past and current Connecticut non-federal internist supply Present and future Connecticut internists supply and need Contribution of non-physician providers.	•FTE supply •FTE need	• Currently available data for specific specialties; • Uncertain flow of physicians in and out of the province; • Classifying specialty based on service provision; • Calculate the supply and need in Connecticut base on the share of US supply and need.
Greuningen et al., 2012 (175)	Supply: stock and flow approach; Demand: estimation.	Graduates; Attrition; Demographic developments; Epidemiological developments; Socio-cultural developments; Change of working hours; Technical developments; Developments regarding efficiency; Developments regarding substitution.	•Number of health professionals •Total FTE of health professionals	• The basic scenario assumed that the demand will increase by 6.0% due to the demographic developments from 2009-2019; • The parameters on the demand side were estimated by experts, however it was not clearly explained how they were being estimated.
Health Workforce 2025 Volume 1, 2012 (176)	Supply: stock and flow approach; Demand: demand/utilisation-based model.	Graduates; Re-entry; Working hours; Migration; Attrition (Death, retirement & career change); Age; Gender; Utilisation rates.	•Headcount of supply, demand and gap •FTE of supply, demand and gap	• Different assumption based on demand scenario.
HRSA, 2008 (63)	Supply: stock and flow model; Demand: Demand/utilisation-based approach.	Number of physicians age & sex; Graduates; Retirement and mortality by age and sex; Disability and career change; Direct patient care hours; Population projections; Insurance distribution.	•FTE active physician •Increase in demand due to aging and growth	• Limitations include using historical data to estimate future trends; • Assume insurance coverage and type, economic growth, and the increased use of NPCs.

Author, year	Design, model type /analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Lee et al., 1998 (177)	Supply: dynamic model; Demand: needs-based model.	Surgeon population; Time spent in direct care; Entry rates of residents; Retirement and mortality rate; Number of office visits; Duration of office visit; Number of procedures; Duration of procedures.	•FTE supply •FTE demand	• Need for large amounts of data; • Accuracy of estimation; • Time and FTEs used as common measure for both supply and demand might be vulnerable to changes in real-life practice and structure of work; • Not able to address distributional issues.
McNutt, 1981 (178)	Supply: dynamic model; Demand: demand/utilisation-based model.	Medical graduates; Practitioner supply; Attrition rates; Morbidity; Prevention; Delphi panel rates.	•Head count of physicians supplied and required by each specialty (Only talked about the concept and analytic framework of the GMENAC model)	• Relied heavily on the Delphi panel to project future demand/utilisation.
Scarbrough et al., 2008 (179)	Supply: stock and flow approach; Demand: needs-based model.	Attrition (Death and retirement); Annual volume of Hepatic-Pancreatic-Biliary (HPB) procedures; Annual number of new HPB subspecialist; Level of fellowship training; Practice patterns of graduating fellows.	•Annual volume of HPB procedures per subspecialist in 2020 •Annual HPB procedure volume per subspecialist in 2020 at current level of fellowship training •Number of fellows needed to train each year to meet demand for HPB surgery	• Reliance on a series of assumptions to determine the current number of practicing HPB subspecialists and the current level of fellowship training; • Assume that none of the fellowship-trained HPB subspecialists first entering the workforce in 2007 would retire, die, or change fields before 2020; • Different scenarios for the projected number of fellows needed to train per year to meet the demand for HPB procedures.
Scheffler et al., 2009 (180)	Supply: trend analysis; Demand: needs-based model.	Number of physicians by country; Projected population.	•Headcount supply, demand, shortage	• Poor data quality in Africa which could undercount healthcare professionals, especially in the private sector; • Supply of physicians is provided from previous estimates and data (Scheffler et al., 2008).
Scheffler et al., 2008 (181)	Supply: trend analysis; Demand: needs-based model and demand-based model.	Historical data on physician numbers 1980-2001; Updated physicians numbers; Economic growth; Historical and projected population; Need-based benchmark: live births	•Supply - per capita physicians •The required headcount of physicians to reach the world health report 2006 goal •Demand for physicians in each country by headcount •Deficit or surplus by headcount	• Need estimated only reflects one aspect of healthcare delivery; • Projection of demand and supply rely on trends of either economic growth or physician per capita.

Author, year	Design, model type /analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Shipman et al., 2004 (182)	Supply: stock and flow approach; Demand: benchmark.	Number of paediatricians by age and sex; Annual number of graduating trainees by age and sex; International medical graduates (IMGs); Death and retirements; Population; Current proportion of outpatient office visit by children to paediatricians; Productivity; Change in work effort.	•FTE General paediatricians •Child population	• Uses different key assumptions for projection, mainly have a set rate for different variables; • Assume that 25% of noncitizen IMGs will not stay in the US workforce after completing training.
Smith et al., 2010 (183)	Supply: stock and flow approach; Demand: demand/utilisation-based approach.	Age-, sex-, race-, population projections; Age-, sex-, race-, radiotherapy utilisation rates; Age-stratified and sex-stratified life-tables; Number of current board-certified radiation oncologists, 2009 residency graduates and 2010 to 2013 expected to graduates; Age- and sex-stratified proportion of radiation oncologists practicing full time, part time, and not practicing.	•Total number of patients receiving radiation therapy in 2020 •FTE radiation oncologists in 2020 •Size of residency training classes to have supply equal demand	• Extent the current supply of oncologists can accommodate increased patient volume; • Estimate of modest changes in radiation therapy practice patterns may impact patient throughout without compromising quality, future technologies.

Author, year	Design, model type /analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Starkiene et al., 2005 (184)	Supply: stock and flow approach; Demand: needs-based model and demand/utilisation-based model.	Population projections; Mortality; Retirement; Migration; Drop out from training; Enrolment numbers of trainee.	•FTE-to-population ratio by different scenarios in supply and demand	• Used different assumptions to manipulate supply and demand scenarios; • Retirement Scenario 1: The retirement age was set to be 66 years and it was assumed that one fifteenth of the group of FPs aged more than 50 years would retire annually; • Retirement Scenario 2: The retirement age was set to be 71 years and it was assumed that one fifteenth of the group of FPs aged more than 55 years would retire annually.
Teljeur et al., 2010 (185)	Supply: stock and flow approach; Demand: demand/utilisation-based approach.	GP visit rates; Age-sex rates of GP attendance; Population projection 2009-2021; Mortality rate for higher professionals; Work practice; Services provided; Practice structure; Overseas graduates; Education/training; Retirement; Nurse substitution.	•GPs needed to meet population demand •GP numbers by different supply scenarios	• Nurse substitution Scenario 1: Nurses were equivalent to 0.25 FTE GPs; • Nurse substitution Scenario 2: Nurses were equivalent to 0.5 FTE GPs; • Assume that the number of GP vocational training places would increase by 20% in 2011; • Later retirement has been considered; • Lack of regional data resulted in failing to test potential impact of each intervention on geographical differences.

Author, year	Design, model type /analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Weissman et al., 2006 (186)	Supply: stock and flow approach; Demand: needs-based model and demand-based model.	Age and sex distribution of anaesthesiologist population; Employment status (full-time/part-time); Country of medical school education; Last anaesthesiologist residency; Professional status (resident, certified specialist anaesthesiologist); Medical school academic appointment; Historical and projected age distribution and birth rate of the Israeli population; Immigration data on physicians; Physicians required per capita; Number of surgeries per anaesthesiologist.	•Anaesthesiologists per 100000 population •New anaesthesiologists needed	• Based on status quo of 10.8 anaesthesiologists per 100000 population.
Yang et al., 2013 (187)	Supply: stock and flow approach; Demand: population-based analysis.	Population growth; Number of plastic surgeons certified in 2010; Retirement; Graduate; Growth of the number of invasive and non-invasive cosmetic procedures.	•Headcount of practicing plastic surgeons •Headcount of plastic surgeons needed	• Only focus on plastic surgeons in US; • The number of new graduates would be constant; • The number of trainee positions would be static; • All practicing plastic surgeons would retire after 35 years' post residency work.

Nurses

Author, year	Design (Model type /analysis)	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Supply model				
Buerhaus et al, 2000 (93)	Using retrospective analysis of employment trends to project long-term age and employment of RNs (Trend analysis)	Forecast of US population through 2020 by age; The propensity of individuals from a given cohort to work as RNs; The relative propensity of RNs t work at a given age.	•Supply projection, 2001-2020. •Annual FTE employment of RNs in total and by single year of age	• Future cohorts will enter nursing at a rate similar to current cohorts; • Changes of the workforce over time only depend on the age of the cohort.
National Health System, 2008 (92)	Dynamic model	Annual growth in 3 year pre reg commissions; FTE/Head count; Attrition; New registrants; International recruitment; Return to practice change; Other joiners; Other leavers;	•Number of registered nurses in 2008-2016	• Annual growth in 3 year pre registration commissions based on WRT assumptions; • FTE/Head count based on historic trend; • International recruitment based on 3-year average;

Author, year	Design (Model type /analysis)	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Demand models				
Ghosh et al, 2005 (101)	Computer-based model, given certain prescribed patient-nurse ratios (Benchmarking)	**In-patient units:** bad capacity, bed occupancy rate, and the percentage share of patients in each unit according to an accepted patient classification system. **Outpatient Department**: Required physical allocation, Total OPD working days in a year, Total working days/nurse/year; **Operating theatres:** planned OT shifts per week, number of weeks per year, nurses per OT per shift, Total working days/nurse/year; **A&E:** Nurses/shift, Number of shifts in a day, Number of days in a year, Total working days/nurse/year; **Renal dialysis:** Number of sessions/station/week, Number of stations, Number of weeks in a year, Nurse/station, Total working days/nurse/year. Sickness, maternity & deputation leave.	•Overall nurses required adjusted for sickness, maternity & deputation leave.	• No variation included, all parameters are constant over years.

Author, year	Design (Model type /analysis)	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Mixed models				
Al-Jarallah, et al. 2009 (100)	Supply: Dynamic model. Demand: Projected by using the average nurse-to-population ratio for 1994-2006. (Benchmarking)	Supply: Graduates. Demand: Population growth; Nurse-to-physician ratio.	Workforce projection, 2007-2020. Supply: •Number of nurses. Demand: •Number of nurses needed.	• Changes in healthcare policies or nursing education can greatly affect the workforce.
Auerbach, et.al. 2012 (94)	Supply Demand: Utilisation-based model	Hours worked; Utilisation of services; Sector; Education; Marital status; Age group; Poverty; Insurance status; Race/ethnicity classification; Number of RN and NP;	Supply •Number of Nurse Practitioners (NP) and RN specializing in SRH. Demand •Utilisation of SRH services	• Different assumption used for various scenarios to predict the workforce for NPs in SRH. • Only focus on SRH service.

Author, year	Design (Model type /analysis)	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Canadian Nurse Association. 2002 (110)	Supply: Dynamic model. Demand: Need-based model and utilisation-based model.	Supply: Age; Sex; Population; Working hours; Graduates; Retirement; Migration Demand: Population;	Workforce projection, 2011 and 2016. Supply: •Number of RNs by age; •Percentage of RNs employed in Nursing by age. Demand: •Number of employed RNs required.	• Assume the average utilisation of services at any given age remains constant.
Health Resources and Services Administration, 2007 (107)	Supply: Measuring RN supply at the county level taken from the 2000 U.S. Census data. Demand: Utilisation-based model and benchmarking. Simplified Nurse Demand Model from HRSA's models	Population; Number of registered nurse; Short-term in-patients days; Long-term in-patient days; Psychiatric hospital in-patient days; Nursing home unit in-patient days; Outpatients visits; Emergency department visits; Population demographic; RNs per 100 hospital beds; Local nursing wages; Numbers of nursing schools and graduates; Number of new RNs passing exam; Turnover rates; Vacancy rates; Hard-to-fill positions; Staffing ratios; Poor facility outcomes; Case mix and acuity; Worker satisfaction; Turnover leadership;	Demand: •Utilisation: in-patient day. •Staffing ratio: Projected RNs per 100000 age-adjusted population, RNs per in-patient days, and RNs per visits, etc. •RN demand by county: staffing ratio*utilisation.	• Assumes that current staffing patterns at the national level reflect a balance of supply and demand, differences within types of care in factors such as patient acuity do not vary substantially across counties, and RN commuting patterns are similar to the commuting patterns of other workers in terms of county flow and outflow.

Author, year	Design (Model type /analysis)	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Health Resources and Services Administration 2002 (65)	Supply: Dynamic model Demand: Project the required nursing services by forecasting the future staffing intensity. (Benchmarking)	Supply: Graduates; Attrition; Aging of RN workforce; Decline in relative earnings; Alternative job opportunities. Demand: Population growth and aging; Per capita demand for healthcare; Trend in healthcare financing (health insurance); Workload by settings; Staffing intensity	Workforce projection, 2000-2020. Supply: •Number of FTE RNs by states •Employment distribution by settings Demand: •Number of FTE RNs by states	• Applying national estimate to the State level
Health Workforce Australia 2012 (95)	Supply: Dynamic model. Demand: Utilisation-based model and benchmarking.	Supply: Graduates; Migration Retirement; Illness and death; Career change; Working hours; Demand: Area of practice; Productivity; Working hours;	Workforce projection, 2009-2025. Supply: •Projected Number of nurse headcount. Demand: •Acute care nursing: number of bed-days; •Emergency care nursing: number of attendances at emergency departments; •Midwives: calculated from the total number of projected births based on the actual number of births from 2006 to 2008 by population projection ratio from 2009 to 2021.	• Only headcount numbers were presented in the report.

Author, year	Design (Model type /analysis)	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Health Workforce Information Programme, 2009 (188)	Supply: Dynamic model. Demand: Need-based model.	Population growth; Age; Surgical intervention; Career changes; Job patterns; Education; Outflows; Sectors (public and private);	Workforce projection of perioperative nurse (PN), 2009-2031. Supply: •Number of PN by sectors Demand: •Number of PN by sectors	• Only focus on perioperative nursing. • Assumes there will be an increase in the scope of practice for nurses. Also assumes that more non-nursing occupation groups will perform support roles for both medicine and nursing.
Juraschek et.al, 2011 (189)	Supply: Trend analysis. Demand: Linear Regression Model and Trend Analysis.	Population; Age; Personal health expenditure; FTE; RN job shortage ratios; RNs per 100,000 population;	Workforce projection, 2008-2020. Supply: •Number of RN jobs Demand: •Number of RN jobs needed	• Supply: the current RN utilisation, the education of new RNs and the national propensity of an individual to choose nursing as a career is the same across states in coming decades. • Demand: Used 2009 national mean as a baseline of demand model means there is no shortage in 2009 but in fact most studies consider the nation to already experience a large shortage. • Using RN jobs as measurement cannot take working hours into account.

Author, year	Design (Model type /analysis)	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
LeVasseur. 2007 (106)	Supply: Dynamic model Demand: Estimating the demand for FTE RNs by calculating the RN staffing intensity by healthcare setting, e.g. RNs/1,000 in-patient days in in-patient setting and RNs/10,000 population in the physicians' office (Benchmarking)	Supply: Based RN population (2000); Migration; Highest level of education; Attrition; State population and potential pool of applicants to nursing programs. Demand: Population uninsured; Medicaid eligible; Per capita income; Demographics; Geographic location; RN staffing intensity by healthcare setting.	Workforce projection, 2005-2020. Supply: •Estimated number of licensed RNs; •Active RN supply; •FTE RN supply. Demand: •Number of FTE RNs	• The supply and demand sides are independent of each other. • The demand model cannot model the substitution between different types of nurses and between nurses and other healthcare professions. • The demand model cannot capture the interaction between settings.
Author, year	**Design (Model type /analysis)**	**Parameters included (population level or individual level)**	**Outcomes**	**Assumptions & Limitations**
Malyon, et al. 2010 (98)	Supply: Dynamic model. Demand: Need-based model and trend analysis.	Supply: Age; Working hours; Graduates; Migration; Retirements; Maternity; Productivity. Demand: Population Burden of disease and injury; Technology impacts.	Workforce projection, 2006-2022. Supply: •Number of Nurse Headcount; •Number of Nurse FTE; Demand: •Number of Nurse Headcount	• Assumption of no productivity changes; • Assumption of no technology impacts.

Author, year	Design (Model type /analysis)	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Moulton et.al, 2008 (105)	Supply: Trend analysis, Nursing Supply Model (HRSA) Demand: Trend analysis, Nursing Demand Model (HRSA)	Age; Sex; Education; Graduates; Retirements; Population;	Workforce projection, 2008-2020. Supply: •Number of FTE RNs Demand: •Number of FTE RNs	• Assumed that the number of new RN graduates will remain constant over time; Trend and rates remain constant throughout.
Moulton, 2003 (109)	Supply and Demand Trend Analysis	Licensed nurses; Graduates; New license by exam, endorsement; Age; Aging population; Variation in strength of the economy; Part-time/full-time nurses;	Workforce projection for direct care nursing, 2003-2013. Supply: •Number of RNs and Licensed practical nurses (LPNs) Demand: •Number of RNs and (LPNs)	• Trend analysis that means the report assumes the trend will be the same rate though 2013.
Murray, 2009 (99)	The HRSA Nurse Supply and Demand Models, revised and updated in 2004, were used to create the Tennessee's projection. Supply: Dynamic model Demand: Project the required nursing services by forecasting the future staffing intensity. (Benchmarking)	Supply: Graduates; Retirement; Migration; Working hours; Renew rate; Demand: Population; Healthcare market conditions; Economic conditions; Patient acuity in different settings; Working hours;	Workforce projection, 2008-2020. Supply: •Number of RN FTE; •Number of Licensed Practical Nurse (LPN) FTE; Demand: •Number of RN FTE; •Number of Licensed Practical Nurse (LPN) FTE;	• The supply and demand sides are independent of each other. e.g. the projection of demand didn't consider the potential supply of nurses.

Author, year	Design (Model type /analysis)	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Rosenbaum, and Ramirez. 2006 (108)	Supply: Dynamic model. Demand: Convert the population projection into numbers of people needing care (Need-based model); Calculate the required FTE RNs per capita (Benchmarking).	Supply: Working hours; Migration; Nurse education; Attrition; Graduates; Demand: Aging population; Working hours;	Workforce projection, 2006-2020. Supply: •FTE Nursing supply Demand: •Estimated FTE RN demand = the units of healthcare usage in each setting * FTE RNs per unit of healthcare usage.	
Spetz. 2009 (102)	Supply: Dynamic model Demand: RN-to-population ratio (Benchmarking) and future hospital utilisation (utilisation-based model)	Supply: Graduates; Retirement; Migration; Working hours; Population. Demand: Population growth and aging; Working hours; Proportion of RNs who worked in hospital setting.	Workforce projection of RNs, 2009-2030. Supply: •Forecasted FTE supply of RNs; •Forecasted employed RNs per 100,000 population; Demand: •Forecasted FTE demand for RNs; •RNs per capita; •RNs per patient day;	• Do not account for short-term changes, e.g. economic conditions. • The utilisation-based model was only for hospital setting. The total demand was calculated by dividing the Hospital FTE by the proportion of RNs who worked in hospital setting.

Author, year	Design (Model type /analysis)	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Srisuphan et al. 1997 (111)	Supply: Dynamic model Requirement: Health demand analysis: Demand-based model determined by econometric projections. Health service development analysis: Demand-based model for public sector and trend analysis for private sector. Nurse population ratio: Demand-based model projected by estimating future economic and population growth.	Supply: Graduates; Attrition. Demand: Future economic; Population; Staff norms; Death rate; Urbanization; Health insurance coverage; Demand components (e.g. nursing services, teaching, and management).	Workforce projection, 1995-2015. Requirements: •Nurse-Population ratio; •Projected demand for nurses by units; •Projected demand for nurses by fields of practice. Supply: •Expected graduates; •Expected number of RNs.	

Author, year	Design (Model type /analysis)	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Tomblin Murphy, et al. 2009 (103)	Simulation model for supply and requirement. Supply: Stock and flow approach. Requirement: Need-based model	Supply: Graduates; Migration; Attrition (Death and Retirement) Relocation; Change of profession. Requirement: Population size and profile Level and distribution of health and illness in the population; Risk factors of illness in the population; Level of service; Productivity; Sectors	Workforce projection, 2005-2020. Supply: •Number of new RNs entrants; •Number of exits from the stock over time. Requirements: •Estimates of RN productivity (e.g. number of acuity-adjusted episodes of care per RN FTE per year); •Estimates of the number of RN required.	• The efforts to support the projection would be significantly hindered by the data reliability and availability relevant to the work of RNs. • Sectors included acute care, long-term care, home care, community and public health.
Wisconsin Department of Workforce Development. 2011 (96)	Supply: constant RN-to-population ratios (Benchmark) Demand: constant nurse staffing intensity and healthcare usage by employment setting and by age. (Benchmark)	Supply: Graduates; Change in labour force participation; Retirement; Death and disability; Migration; Demand: Staffing intensity; Healthcare use by setting and by age;	•Workforce projection, 2010, 2015, 2020, 2025, 2030, 2035. •Headcount and FTE of RNs for direct patient care, broad nursing workforce.	• Assumed that the 2010 RN-to-population ratios would remain constant. • Better data required to determine quality of RN FTE. • Severity of illness or demand by diagnosis.

Dentist

Author, year	Model type/analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Supply models				
Chrisopoulos and Teusner, 2008 (81)	Stock and flow	Baseline number of dentists; Australian university Graduates; Overseas entrants; Return to practice (RTP): return from overseas, return after cessation of practice; Migration; Retirements Death; Alternative career; Study and parental leave.	•Number of dentists; •Dentists-to-population ratio.	• Hard to predict the trends in the future, practice activity of new graduates trained by new schools may be different from previously observed patterns.
Grytten and Lund, 1999 (82)	Dynamic model	Retirement; New entrants;	•Net change in man-labour years 1999-2015	• Assuming the number of new entrant remains constant.
Guthrie, et.al., 2009 (80)	Dynamic Model Plateau, linear, and exponential increases for new graduates; population growth was projected to be linear.	Productivity; Gender mix; Retirement rate; Projection of the number of graduates; Number of new dental schools ; Population growth.	•No. of dentists per 100,000; •Dentist-to-population ratio.	• Assumes that the dental services are delivered largely through private markets subject to the effects of supply and demand and that enrolment in dental schools reflects the rate of return of a career in dentistry in comparison to other options for college graduates

Author, year	Design (Model type /analysis)	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Saman, et.al., 2010 (78)	Poisson regression modelling and geospatial analyses, System Dynamic Model (iThink, iSee Systems, Version 9.1)	Number of dentists retiring per year; Number of dentists entering profession; Population estimates.	•Number of dentists entering profession; •Dentist-to-population ratios	• The dentist-to-population ratio is not a sufficient measure by itself. • Fixed retirement rate at 82 per year, and fixed incoming rate at 55 per year.
Solomon, 2009 (79)	Dynamic Model	Number of graduates; Gender ratio; Retirements; Population; Specialists; Full time and part time.	•Number of dentists working full-time and part-time; •Number of dentists by specialty status; •Number of dentists per 100,000 populations.	• The paper isolates the different parameters and looks at it differently, does not tie in the parameters together
Spencer, et al. 1993 (83)	Dynamic model	Number of new surgeons per year recruited; Wastage rates.	•Number of surgeons; •Population-to-surgeon ratio.	• Wastage rates are not explicitly given, so assumptions not easy to ascertain
Demand models				
Morgan et al. 1994 (85)	Need-based and demand-weighted method.	Age-specific Decayed, missing and filled teeth (DMFT) rates; Prostheses rates; Rates for other dental procedures (not listed); Population projection;	•Required operator-to-population ratio	• Assume DMFT would decline, but at different rates for different age groups, and also rate of decline will decrease. • Assume prosthetic needs would increase. • Other assumptions for changes in demand.
Nash et al. 2002 (84)	Utilisation-based model	Population projection; Assumed yearly % increase in utilisation	•Number of endodontists required	• Assuming different scenario for utilisation increase.

Author, year	Design (Model type /analysis)	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Mixed models				
Australian Research Centre for Population Oral Health, the University of Adelaide, South Australia. 2010 (86)	Supply: stock and flow; Demand: Utilisation-based model.	Supply Recruitment; Retirement; Death; Outflow overseas; Cessation of practice; Practice sectors Demand: People with OMF diseases or conditions; Population.	Supply: •Number of OMF surgeons; •Practicing OMF surgeons per 100,000 populations Demand •Number of services.	• Only focus on Oral and maxillofacial surgeons (OMF). • In/out-flow probabilities stay constant over time. • Changes in demand not directly linked to external factors, e.g. technological advance or increased Medicare funding
Beazoglou, et.al., 2002 (89)	Supply: Dynamic model. Demand: Utilisation-based model.	Specialty distribution; Retirement; New entrant; Types of auxiliaries employed; Population; Income of population; Socio-demographic characteristics Productivity;	Supply •Number of dentists Demand: •Per capita utilisation; •Population-to-dentist ratio; •Number of dentists; •Number of dentists needed to maintain current levels of access to care.	• Assumes that the past rate of productivity improvement will continue for the next 10 years, low sampling due to national surveys. • Population not stratified. • Demand proxied by national expenditure on dentistry
Brown, et al. 2007 (88)	Trend analysis and need-based model	Supply: Female dentists; Productivity; Practice patterns; Demand: Population; Economic buying power; Knowledge and appreciation of dental services; Amount of disease;	Supply: •No of dentists. Demand: •No. of dentists needed.	• Supply: Considered both adjusting and not adjusting for productivity increase.

Author, year	Design (Model type /analysis)	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Gallagher, et al. 2010 (87)	Supply: Trend analysis and dynamic model. Demand: Utilisation-based model.	Supply: percept yearly increase over the previous 9 years; Short-term recruitment drive of over 1,000 dentists; Increased dental student intake; percept of time devoted to older people; percept devoted to NHS patients; percept women dentists; Number of dental hygienists and therapists and clinical dental technicians (CDTs). Demand: Rate of edentulousness; Dental attendance pattern; Treatment rates; General dental services (GDS). Treatment times Treatment type	Supply: •Number of WTE dentists; •Shortfall or surplus of WTE dental staff (not just dentists) Demand: •Total number of treatments; •Total demand for treatment hours; •Per capital demand.	• Supply of government dentists only. • Made various assumptions on which treatment can be performed by hygienists, therapists, and CDT. • Demand, only focus on the population aged over 65.
Try, 2000 (90)	Supply: Dynamic model. Demand: Utilisation-based model.	Supply: Graduates (net inflow); Working hours; Female dentists; Productivity; Demand: Population; Patterns of disease; Dental diagnosis; Age-sex-specific no. of courses of dental treatment;	Supply: •Whole Time Equivalent (WTE) of dentists. Demand: •Number of courses of treatment; •Courses of treatment per WTE dentist.	•Assumed that the proportion of female stays the same. •Assumed that Part-time working becomes more common.

Author, year	Design (Model type /analysis)	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Waldman, 1995 (91)	Simple calculations	Demand: Population projection (state-wise) Population : dentist ratio Assumptions on retirement	Supply: •Number of new periodontists available to practice Demand: •Number of active periodontists needed; •Number of new periodontists needed (to replace retirement);	•Only focus on periodontal patients; •Assumed that 18.6% of graduates are not from the US and will go back. •Assumed that in 2020, all dentists ≥ 40 in 1991 will have retired/died. All dentists < 40 still practicing

Pharmacist

Author, year	Design Model type/ analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Supply models				
Bond, et al. 2004 (114)	Dynamic model	Graduation; retirement	•Net increase in pharmacists from 2000-2020 •Increase in pharmacists who complete residencies from 2000-2020	•Data from a survey in 1998 may not be representative of the healthcare in 2020.
Cooksey, et al. 2002 (116)	Dynamic model	Graduation; Workload (average number of Prescriptions dispensed annually); Working hour; Productivity increase; Percentage of female pharmacist	•Projected pharmacists per 100,000 population ratio in 2005. •Projected female pharmacists (%) in 2005.	•No analysis of urban or rural practice
Johnson, et al.2009 (112)	Dynamic model Pharmacist to population ratio.	New graduate and training capacity; Increasing number of female pharmacist; working hour; Reference period: 2000-2008	•To project target workforce in 2008-2020 by using FTE measures.	•FTE definition: •One who works average 1890 hours per year (40 hours per week times 47.2 weeks per year)
Knapp and. Cultice, 2007 (113)	Stock-flow model	Age; Retirement and death; Graduates; Working hour; Number of female pharmacist Parameters included (population level or individual level)	•Age and gender based pharmacist supply projection 2004-2020.	Assumption: •All the pharmacists would retire by age 75. •The increase of female pharmacist percentage would continue.

Author, year	Design Model type/ analysis	Parameters included	Outcomes	Assumptions & Limitations
Demand models				
Bond, et al. 2004 (115)	Trend analysis (clinical pharmacist)	Pharmacist time (hrs./wk.); Pharmacist time (min/patient); Number of patients who received each decentralized clinical pharmacy service; Working hour;	•Total No. of Clinical Pharmacists FTEs per Hospital needed in 2020 •Total No. of Clinical Pharmacists FTEs needed in 2020	•Data from a survey in 1998 may not be representative of the healthcare in 2020.
Johnson, 2008 (117)	Trend analysis	Graduation rates; Residency training	•Projected the no. pharmacists needed in 2020	•No detail of pharmacist-to-population ratio; no data of gender difference
Meissner, et al. 2006 (118)	Demand/utilisation base	Medicare Part D (Drug coverage); ADI (Aggregate Demand Index); Percentage of costs paid by third-party payer; prescription volume; pharmacist-to-technician ratio; Direct-to-Consumer (DTC); mail order; graduates; retirement; pharmacist wages;	•Projected Aggregate Demand Index (ADI) for 2009. •Prediction of no. of pharmacists needed in 2010. •Prediction of pharmacist shortage in 2020.	•Mainly focusing on drug coverage, not considering other services provided by pharmacists and the expanding roles.

Author, year	Design Model type/ analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Mixed models				
Department of Health and Ageing, Australian Government. 2007 (107)	Dynamic model Demand utilisation model	Supply: Working hour; Graduates; Immigration and emigration; Retirement, death and disability; Inactive workforce Demand: Population growth and ageing; Working hour; Sex- and age-specific ratios of scripts to persons per annum; Productivity of dispensing workforce; Technician-to-pharmacist ratio; Technician equivalence to pharmacist; Community pharmacy share of total service; Further expansion of the role of both hospital and community pharmacist; Number of people attending hospitals; The ratio of pharmacists to hospital separations(discharge or death);	Forecast on annual supply of pharmacist through 2025. Supply: •Total Graduates Active and inactive % (2006) •Active •Inactive •Working outside pharmacy workforce Forecast on Demand: •Community pharmacist •Hospital pharmacist	•Unidentified variables; •Insufficient magnitude of change for some variables, e.g. global financial crisis. Assumption: •2.48% population growth; Community pharmacist: •Ratio of technicians to pharmacists would increase to 0.3 by 2025; •Scripts to persons increase by 0.5% per annum; •Dispensing productivity stays constant. Hospital pharmacist: •Highest estimates of future growth; •With declining ratio of separations to hospital pharmacists (ceases in 2012)

Author, year	Design Model type/ analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Fraher, et al. 2002 (123)	Trend analysis Dynamic model.	Demand: Population growth and ageing; Insurance (prescription drug coverage); Direct-to-consumer (dtc) advertising; Supply: Age; Gender; Working hour; Graduates	Demand: •Prescriptions dispensed per population Working hour per week (1989-1998) •Male •Female	•Not projection model
Health Resources and Services Administration. (HRSA) 2008 (121)	Demand/utilisation base Dynamic model	Demand: Population growth and aging; New and more complex pharmaceuticals; Evolving societal attitudes; Increased affordability and Availability of generic drugs; Increase in pharmaceuticals for Chronic conditions; Role of pharmacist; Supply: Number of graduates (local and overseas); Male-female ratio; Working hour; Attrition	•FTE shortfall projection •Examine the adequacy of previous pharmacist supply projection. •Projection for total pharmacist supply. •Projected male-to-female ratio in workforce.	Assumption: •Moderated prescriptions /capita growth; •No growth in educational capacity •Factors such as technology development and the number of graduates are uncertain.

Author, year	Design Model type/ analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Health Resources and Services Administration. (HRSA) 2000 (126)	Trend analysis	Demand: Volume of prescription medication dispensed (in different settings); Population growth and aging; Increased third-party prescription coverage; Growth of the economy; Expending roles; Introduction of new and innovative drug therapies; Direct-to-consumer marketing; Increased number of prescription providers Supply: Graduates; Male-female ratio; Losses due to death, retirement and leaving practice; Region; Working hour	•Supply of Active Pharmacists (pharmacists per 100,000 resident U.S. population) •Per cent of female active pharmacists	•No projection of the demand for pharmacists.
Knapp, et al. 2002 (190)	Trend analysis Dynamic model	Demand: Unemployment rates; Retail prescription growth rate Supply: Number of graduates	•Looked at ADI trend from year 1999=2010 •Pearson Correlation between ADI and below factors: •Unemployment •Graduates •Prescription growth rate	•Data unavailability, e.g. retail prescription data for 2010 and actual graduate data for 2010.

Author, year	Design Model type/ analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Knapp, et al. 2005 (124)	Trend analysis	ADI (5-point rating system): 5= high demand for pharmacists, difficult to fill positions, 4 = moderate demand, some difficulty filling positions, 3 = demand in balance with supply, 2 = demand is less than the pharmacist supply available, and 1 = demand is much less than the pharmacist supply available.	•Rating distribution among different regions:	•The usefulness of the ADI is limited by the fact that panellists may choose different ratings for the same scenario. •Replacement panellists may not rate the severity of the shortage the same as did the original panellists within the same organization.
Knapp. 2002 (125)	Dynamic model	Graduation; Working hour; improvement of therapy; growth of distance therapy; increased intensity of hospital; growth in size and complexity of hospital system; Functional area (order fulfilment, primary care, secondary & tertiary care and non patient care)	•Current use of FTE pharmacist 2001 •Projected need for FTE pharmacist 2020 •Total estimated FTE supply •FTE pharmacist shortfall	•Mainly about the factors needed to be considered; •Projection model was not clearly described.
Koduri, et al. 2009 (120)	Benchmark Dynamic model Design Model type /analysis	Pharmacist to population ratio Expanded roles; Prescription volumes growth; Population growth and aging; Insurance coverage; DTC Marketing; Expiring drug patents;Attrition Number of graduates; Working hour; Gender FTE adjustment	•Projected future trends for FTE demand and supply. Outcomes	Assumptions: •79 pharmacists would enter the field each year (in Utah); •Each female pharmacist provides 0.79 FTE of pharmacy services;

Radiographer

Author, year	Design Model type /analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Supply model				
Reiner, et al. 2002 (191)	Supply description	Type of facility; Facility size; Modality;	•Average FTEs •Average number of FTE for different modalities •Radiography •CT •Ultrasonography •MRI •Nuclear medicine •Mammography •Interventional/angiography	Limitations: •Only give out the average FTE numbers in different types of facilities; •Do not have a trend of FTE numbers.
Wing, et al. 2009 (146)	Age cohort flow model	Population growth; New entrants; Attrition; Age; Working hour;	•Projection of FTE Supply of Radiologic Technologists •Status Quo Projection •Projection on radiologic Technologists per 100,000 Women	Assumptions: •Future resource inputs proportional to current practitioner-to-population ratio. Limitations: •Do not account for productivity increase; •Only focus on mammography.
Mixed model				
Bingham, et al. 2002 (192)	Demand: Trend analysis Supply: Trend description	Demand: Extension of NHS Breast Screening Programme from females; skill mix (radiographer assistant); population ageing and growth; WTE Supply: Graduates; Working part-time and work-life balance; Retirement; Student attrition; Career progression	•Projection of overall radiography workforce demand (2002-2006 plan): •Diagnostic •Therapeutic Projection in Supply: •overall radiographers •diagnostic radiographers •therapeutic radiographers •Projected supply against projected demand (2002-2006)	Assumptions: •8% of attrition rate for radiographer students; •All radiographers would retire on earliest eligible retirement age (60 years); •Workforce capacity lost due to increase of part-time working and work-life balance (1.75%), would increase to 2.15% (0.1% per annum.

Author, year	Design Model type /analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Centre for Workforce Intelligence. 2012 (147)	Trend analysis	Data from DH: Age; Graduates; Field of practice; Training attrition; Retirement; Ageing population; Increased demand in related groups;	•Project increase in demand •Projection available workforce supply from 2010 to 2016 in headcount and FTE	Limitations: •Only focus on diagnostic radiographers.
Patterson, et al. 2004 (193)	Demand: Population projections Supply: Trends description	Demand: Aging workforce and population; Hospital radiographer employees and vacancies Supply: Total license grows; Retirement; Proportion of active licensees currently practicing; Aging workforce and population; Education capacity	Supply: •Active licensees (currently practicing) •Projection on retirement •Demand (Vacancies)	Assumptions: •A demand of 69.0 providers per 100,000 populations. Limitations: •Scarcity of data related to the state's radiographer workforce; •Size of radiographer workforce is small, making the projections more volatile. •Unavailable data, e.g. FTE, migration in and out of state. •The data of demand projection was based on hospital radiographer only. •Active license may not be able to represent the active practitioners.
Victorian Department of Health. 2010 (194)	Demand: demand/utilisation model Supply: Stocks and flow model	Working hour; Graduates; Attrition; Immigration; Adjusted training requirement;	•Projected FTE Demand: 2009 - 2030 •Projected number of graduates: 2010-2029 •Projected FTE Shortage (based on current trends in workforce supply)	Limitations: •Assuming that no significant changes in radiation technology;

Optometrist

Author, year	Model type /analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Supply models				
Bellan, et.al. 2007 (195)	Dynamic (Stock and flow) model	Retirement; Death; Emigration; Age; Sex; Graduates; Population.	•Number of FTEs; •FTEs per 100000 populations; •Percentages of female FTEs.	•Assumes a status quo scenario in terms of attrition and gain factors.
Demand based utilisation models (includes 'need', 'requirement' etc.)				
Tuulonen, et.al. 2009 (137)	Computer simulation model using system dynamics approach	Number of cataract, glaucoma, diabetic retinopathy, and macular degeneration; Cost of those disease; Number of ophthalmologists; Number of physicians; Population data	•Number of patients; •Service increase (e.g. Cataract surgery and Bilateral surgery)	•Different number of assumptions based on what kind of disease they are looking at, have various scenarios
Mixed models				
Australian Institute of Health and Welfare. 2000 (196)	Trend analysis	Age; Number of optometrists; Number of optometrists; Migration; Sex; FTE; Population demographics; Graduates; Utilisation of services;	Supply: •Number of FTEs optometrists; Demand: •Number of FTEs needed;	•Assume that there will be no significant change from the current pattern of use of optometrist services, the number of graduates, workforce participation and average number of services per optometrist.

Author, year	Model type /analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Kiely, et al 2010 (197)	Supply: Dynamic model Demand: Utilisation-based model	Graduates; Retention rates; Immigration; Age; Attrition; Population; Service utilisation rates	Supply: •Number of FTEs; •Percentage of female optometrists. Demand: •Number of FTEs required	•Assumes different scenarios for practice and how it affects supply and demand.
Lee, et.al 1998 (198)	Supply: Unclear Demand: Need-based model	Subspecialty; (not very specific on how they calculated)	•Number of FTEs by subspecialty	•Does not specifically show how the FTE were calculated with certain parameters
Pick, et.al. 2008 (141)	Trend analysis	Retirement age and rates; Graduates; Retention rates; Number of ophthalmologists; Service hours; Population	Supply: •Total number of ophthalmologists Demand: •Require number of ophthalmologists	•Assumes no change to working hours or the number of trainees, lack full-time equivalent data for the workforce, did not collect gender-specific data for the workforce, did not consider overseas

Medical Laboratory Technician

Author, year	Model type /analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Supply models				
Canadian Institute for Health Information (CIHI) 2010 (131)	Supply description	Graduates; Working hours; Age; Gender; Pass rate of the certification examinations; Field of practice; Place of employment;	•FTE of active registrations in the previous years; •Proportion of professions by field of practice.	Assumptions: •Standard full-time weekly hours of 37.5 hours.
Mixed models				
Health Resources & Services Administration2005 (199)	Supply and demand:	Supply: Population; Graduates; Career attraction (wages and career growth); Demand: Demographics; Changing biomedical and information technologies; Utilisation of laboratory test;	•Shortages by types of workers and geographic area.	Limitations: •No numbers of supply and demand.

Chiropractor

Author, year	Model type /analysis	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Supply models				
Davis, et al. 2012 (129)	Supply description	Geographic variation; Age; Adult population; Population educational levels;	•Total number of Chiropractors; •Chiropractors per capita.	Limitations: •Lack of information about working hours; •Only included the chiropractors in Medicare.
Davis, et al. 2009 (130)	Supply description	Age; Adult population; Graduates;	•Total number of chiropractors; •Chiropractors per 10,000 adult population (age>18).	Limitations: •Lack of information about working hours and number of visits.
Mixed models				
Institute for Alternative Futures 2005 (128)	Supply: stock and inflow Demand: need-based model	Ageing; Adult population; Graduates; Retirement; Technology; Conditions treated (e.g. low-back pain, neck pain); Types of practice (e.g. solo private practice)	•Percentage of using chiropractic care annually (age>18); •Percentage of chiropractic care provided to patients below 18 annually; •No. of practicing chiropractors; •Patient visits per week.	Assumptions: •Four alternative future scenarios were being described and used for projection.
Whedon, et al. 2012 (127)	Supply and utilisation description	Geographic variations; Population (aged 65 to 99);	•Chiropractors per 100,000 population (2008); •Annual services per chiropractic user; •Chiropractic users per 1000 Medicare beneficiaries.	Limitations: •The chiropractic use may be underestimated due to the availability of chiropractic service in veteran's administration health service.

Physiotherapist

Author, Year	Design (Model/type analysis)	Parameters included (population level or individual level)	Outcomes	Assumptions & Limitations
Supply models				
WRHA, 2002 (135)	Dynamic Model	Position/vacancy data; Retirement data; Graduates; New registrants	•Vacancy percentage by Equivalence of Full Time	•The calculation of FTE, it assumed that all persons employed were full time. •It is not known whether any of the positions are filled by therapists working at more than one location.
Mixed models				
Breegle, 1982 (144)	Supply: Dynamic Model Demand: Trend Analysis Need Model	Population; Number of patient visits a year; Average admissions; average length of stay; Possible outpatient visits per year; Estimated home-bound patient visit needs Practitioners; Graduates;	•Ratio of PT per 10,000 Population	•Trend analysis: assuming factors influencing the historical trend remain constant. •Health-Needs Method: assuming one third of the possible visits were physiotherapy related, non-institutionalized people received 0.87 home visits. •Supply based on the historical data.
American Physical Therapy Association, 2012 (200)	Supply: Dynamic Model Demand: Linear Regression Analysis	Number of licensed PT; Graduates; International PT; Attrition/retirement rate; Working hour per week; Population with insurance; Vacancy rate	•Full Time Equivalent	•Number of international PT will remain constant. •Constant attrition rate. •The percentage of insured population is based on current rate. However the percentage can change based on the Affordable Care Act. •Vacancy rate only reflects the situation in 2010.
Zimbelman, 2010 (142)	Supply: Dynamic Model Demand: Linear Regression Analysis	Number of PT available job vacancy; Projected population; Personal healthcare expenditure(PHE); Likelihood of being employed; Population; Baseline number of PT	•Shortage ratios per 10,000 people	•The demand model is determined only by age and population growth. 2. Assumption of linear growth was made; •Does not incorporate workplace settings, part-time or full-time employment status;

Occupational Therapist

Author, year	Design (Model type/analysis)	Parameters included	Outcomes	Assumptions & Limitations
Supply models				
Salvatori et al, 1992 (134)	Dynamic Model	Population level data: Actual 1988 employment data; annual inactivity rate; Graduates; Immigration; Re-entry figures; A part-time to full-time FTE ratio	•Number of Occupational Therapists	•Numbers may not be accurate. •Many rates kept constant over years.
WRHA 2002 (201)	Dynamic Model	Individual level data: Current position and vacancy, predicted new graduates, Past retention rate for new graduates, new registrants over the past 5 years, retirement rate.	•Vacancy rate by Equivalence of Full Time	•Information was based on previous data and representing status at one point in time, and only based on requirements for the year of 2001. •Difficult to measure the impact of the availability of work within private sector, with the possibility of improved benefits and flexibility.
Demand based utilisation models (includes 'need', 'requirement' etc.)				
Mirkopoulos et al, 1989 (133)	Demand Analysis by growth per year	Population level data: Current number of paid full-time and part-time OT's, Vacancy numbers, Attrition rates in physiotherapy, hospital average growth rate, Home care average growth rate for OT.	•Full Time Equivalent	•It was assumed that the factors affecting attrition would be very similar for physiotherapy and occupational therapy. •Baseline data didn't represent the whole picture, therefore there was underestimate of the true requirement projection.
Mixed models				
Morris 1989 (136)	Supply: Dynamic Model Demand: Analysis by growth per year	Individual level data: Predicted number of additional positions by respondents from different sectors, Projected population in Georgia, national population ratio, Average annual number of graduates between 1980-1986.	•Full Time Equivalent	•Future demand was based on professions prediction. •All Georgia graduates accept employment within the state, and no separations from the work force occur.