

A complex systems approach to health workforce modelling: Simulating regional psychology workforce capacity and mental healthcare access to 2050

Adam Hulme

a.hulme@uq.edu.au

The University of Queensland

Caley Tapp

The University of Queensland

Eryn Wright

The University of Queensland

Fiona Charlson

The University of Queensland

Tegan Hopkins

The University of Queensland

Birgit Kopainsky

University of Bergen

Jefferson K. Rajah

University of Bergen

Research Article

Keywords: System Dynamics, psychology workforce, mental health services, Better Access, Primary Health Networks, regional health planning

Posted Date: October 22nd, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10963867/v1>

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Additional Declarations: No competing interests reported.

Abstract

Background.

Mental health workforce projections estimate future workforce supply and demand for services but seldom represent nonlinear feedback and behavioural adaptation through which population need, workforce capacity, service access, and system performance change over time. We examined these dynamics within a community-based psychological treatment pathway funded through Australia's universal health insurance system and delivered by a Primary Health Network in southern Queensland.

Methods.

We developed and calibrated a 2013–2050 system dynamics model using workforce, Medicare-funded psychological therapy and population time series data. Model parameters were optimised against observed data, and uncertainty analyses identified plausible parameter combinations. The calibrated model generated a business-as-usual (BAU) projection and three stress test scenarios: (i) a future ceiling on workforce recruitment; (ii) increasing pressure from rising mental ill-health driven by compounding effects on onset; and (iii) their combination. Paired simulations compared each stress test with BAU.

Results.

The model reproduced broad historical trajectories. By 2050, mean paired differences from BAU under the recruitment ceiling were – 163 clinical FTE [-420, 0.0] and – 4,800 monthly services [-12,500, 0], with poorer access and workforce indicators despite a smaller visible treatment queue. Compounding onset pressure increased the population living with mental ill-health by 32,100 [24,100, 42,600]; workforce and services expanded but did not fully offset rising need. Combined pressures produced the clearest deterioration: +38,200 people living with mental ill-health [24,900, 55,200], -147 clinical FTE [-421, 84] and – 4,000 monthly services [-12,500, 2,900], alongside lower supply-demand balance and greater care-seeking suppression and pipeline attrition.

Conclusions.

BAU stability depended on recruitment keeping pace with demand. The combined pressures produced the clearest overall system-wide deterioration and showed that smaller queues can coexist with poorer access. Interpreting FTE, service volume and waiting alongside care-seeking, attrition and workforce conditions could support more complete whole-of-system planning. More broadly, these findings suggest that human resources for health planning may benefit from approaches that explicitly represent feedback processes, delays, behavioural adaptation, and other emergent system dynamics that influence how workforce capacity, service demand, and access evolve over time.

Introduction

Access to psychological treatment in community mental healthcare depends not only on workforce availability, but also on the complex interactions among population need, service demand, treatment access, and the behaviours and perceptions of practitioners, patients and communities^{1,2}. Community mental healthcare must respond to a broad spectrum of needs, from supporting positive mental wellbeing³ and an individual's ability to cope and function in everyday life⁴, to providing care for those experiencing diagnosable mental disorders⁵. Meeting these needs requires sufficient workforce capacity alongside effective service delivery and accessible treatment pathways. However, in Australia, the National Mental Health Workforce Strategy⁶ and Psychology Supply and Demand Study⁷ identify existing and projected shortfalls in the psychology workforce. Alongside increasing mental health consultations reported in Australian national survey data⁸, these shortfalls may contribute to delayed care, attrition from treatment pathways, workforce strain and changes in care-seeking behaviour. These consequences may, in turn, affect workforce capacity and service demand, creating feedback processes that reinforce or alleviate shortages over time⁹.

System dynamics is a modelling and simulation approach that captures the feedback mechanisms and adaptive behaviours inherent in complex health systems, including mental healthcare, within an integrated causal framework^{10–14}. In this study, system dynamics is used to examine the pathway from primary healthcare to community-based psychological treatment in the Darling Downs and West Moreton (DDWM) Primary Health Network (PHN) region of southern Queensland, Australia. The model represents psychology workforce supply, service demand, and treatment access as dynamically interconnected components of the regional mental healthcare system, enabling investigation of how interactions among these factors influence access to care over time. Following calibration against historical data, the model generates a business-as-usual (BAU) projection to the year 2050 and explores three illustrative stress scenarios. First, a workforce recruitment ceiling represents potential constraints on workforce attraction, training and entry^{6,7}. Second, a progressive increase in mental ill-health onset is motivated by evidence that chronic stressors can increase population mental health burden^{15,16}, and by calls for systems-oriented planning in response to increasing environmental and climate-related disasters^{17,18} which are of growing concern in the study region. Third, the combined scenario incorporates both stressors.

Beyond scenario exploration, a particularly novel methodological contribution of this study is the explicit integration of behavioural and experiential “soft” variables as endogenous components of the model. These variables include societal, clinician, and patient perceptions of system performance, as well as workforce morale, fatigue and burnout, professional passion and experience, mental health service quality and intention to leave professional practice. Although system dynamics has long incorporated qualitative evidence^{13,19}, methods for operationalising, quantifying, and parameterising soft constructs remain underdeveloped generally^{20,21}, and in health and workforce planning specifically. Here, we represent the nonlinear relationships between these constructs and observable system conditions through parameterised response functions suitable for calibration and sensitivity testing²², building on studies that have linked qualitative conditions with operational data under uncertainty^{23,24}. This study therefore extends conventional supply-demand projections in human resources for health^{7,25,26}, and responds to calls for more integrated simulation-based approaches capable of representing the dynamic complexity of health workforce systems, including the social dynamics that shape behaviour within them^{2,27}.

Accordingly, this study has two aims. First, we examine how regional population need, psychologist workforce capacity, utilisation of services subsidised through Medicare (Australia’s universal publicly funded health insurance scheme), and endogenous behavioural and experiential responses interact over time, using historical trajectory reproduction to evaluate model behaviour and establish a conditional BAU trajectory to 2050. Second, we test how the three stress-test conditions described affect workforce capacity, service access and unmet need relative to BAU, and derive implications for regional workforce planning.

Methods

Study design and setting

We constructed a system dynamics model of non-acute, community-based mental healthcare in the DDWM PHN catchment in southern Queensland, Australia. In 2022, the region had an estimated resident population of 621,404 distributed across 95,642 km²²⁸ and 12 Local Government Areas spanning urban, regional, rural, and remote settings²⁹. PHNs assess local needs and commission primary and community healthcare services³⁰.

Medicare is Australia’s universal publicly funded health insurance scheme³¹. The model focuses on psychological treatment subsidised through the Medicare Benefits Schedule (MBS) under the Better Access initiative³², specifically services delivered by general and clinical psychologists in private community practice. Recovery through services outside this pathway was represented through aggregate ‘other care’, without specifying its workforce capacity or service activity.

The model was developed iteratively by a multidisciplinary team with expertise in system dynamics, mental health epidemiology and service systems, and direct psychology practice within the DDWM region. Its structure was informed by published evidence, administrative data, the National Mental Health Service Planning Framework (NMHSPF)³³, the Better Access initiative³², and structured deliberation within the research team.

Model structure and dynamics

The model comprises seven interacting sectors representing: (i) population demography; (ii) mental ill-health onset and resolution; (iii) care-seeking and primary mental healthcare; (iv) referral and treatment waiting; (v) psychological treatment and pathway exit; (vi) psychologist workforce, productivity and service capacity; and (vii) delayed behavioural responses to workforce and service conditions. Figure 1 presents a simplified stock-and-flow diagram and model narrative. The complete simulation model is publicly available on isee Exchange^{TM34}. Relationships involving behavioural and experiential constructs were operationalised using delayed, bounded and nonlinear response functions, drawing on established approaches to representing qualitative evidence and behavioural assumptions within system dynamics models^{13,19 20,21 22}.

<insert Fig. 1 about here>

The model represents the population in aggregate, without age stratification. Mental ill-health onset is therefore modelled as a population-average monthly transition hazard rather than age-specific incidence. The model does not distinguish subgroup differences in clinical need, service eligibility or treatment pathways. A calibrated Medicare utilisation fraction translates total modelled treatment activity into its MBS-observable component.

The access pathways were informed by Better Access evidence on provider capacity and barriers to progression from referral to treatment³⁵. The workforce strain pathways reflect evidence that workload and time pressure contribute to burnout among applied psychologists³⁶, and that therapist burnout is associated with poorer treatment outcomes³⁷. The broader causal structure is consistent with job demands-resources theory and Australian evidence linking workload, burnout and turnover^{6,38–40}.

The key equations underpinning model behaviour are provided in Additional file 1 (Key model equations), complementing the conceptual overview presented in Fig. 1. Among these, the supply-demand indicator (SDI) serves as a key measure of system capacity, calculated as the ratio of baseline people-equivalent treatment capacity to the combined population waiting for or receiving treatment. Values below one indicate that treatment demand exceeds available capacity, signalling workforce constraints and reduced service accessibility. The complete set of equations, including graphical and parameterised response functions, is provided in Additional file 2 (Full model equations and documentation), supporting transparency and reproducibility^{41,42}.

Implementation

The model was implemented in Stella Architect version 4.3⁴³ and simulated from January 2013 to January 2050 (444 months) at a time step of 0.25 months using fourth-order Runge-Kutta integration. Verification assessed the model boundary, causal structure, equations, parameter plausibility, dimensional consistency and extreme-condition behaviour, using published evidence, administrative data and multidisciplinary expertise. Historical behaviour reproduction was assessed against the five calibration time series. Ensemble visualisation and statistical analysis of exported outputs used SDgraphing⁴⁴.

Calibration drew on five observed time series spanning the major model sectors: (i) psychologist clinical full-time equivalent (FTE); (ii) adjusted service rate; (iii) patients receiving primary mental healthcare; (iv) total population; and (v) patients receiving community treatment. Workforce data were obtained from the National Health Workforce Dataset and Health Workforce Data Tool^{45,46}, service and patient data from Australian Institute of Health and Welfare (AIHW) Medicare mental health reporting⁴⁷; and the population anchor from official DDWM-PHN sources^{28,29}. Table 1 details the observed periods and transformations.

Table 1
Time-series calibration targets

Element	Type	Units	Period	Source	Description
Psychologists clinical FTE	Stock	clinical FTE	Jan 2013–Jan 2024 (12 annual anchors)	NHWDS via HWDT	Annual clinical FTE for psychologists in the DDWM PHN region, filtered by profession and geography. Clinical FTE represents service-delivering workload rather than practitioner headcount or registration endorsement. The model represents this series as a single effective psychology workforce stock. Annual anchors were linearly interpolated to generate monthly calibration targets.
Adjusted service rate	Converter	services/month	Jan 2014–Jan 2024 (11 annual anchors)	AIHW analysis of MBS data	Annual counts of Medicare-subsidised psychological services relevant to the represented pathway were divided by 12 to obtain average monthly service volumes and linearly interpolated between anchors. The series calibrated the endogenous adjusted service rate, which combines baseline workforce service capacity with behavioural productivity effects before conversion to people-equivalent treatment capacity. It captures activity claimed under the selected MBS items rather than all psychological care or practitioners' complete clinical workloads.
Patients receiving primary mental healthcare	Stock	people	Jan 2014–Jan 2024 (11 annual anchors)	AIHW analysis of MBS data	Annual counts of people receiving selected Medicare-subsidised GP mental health services were divided by 12 to obtain monthly-equivalent values and linearly interpolated between anchors. The series was used as a pragmatic proxy for the active primary mental healthcare stock rather than as a literal point-in-time census of concurrent GP caseload. Mental healthcare billed under other MBS items or provided outside Medicare is not captured.
Total population	Summing converter	people	Dec 2016–Dec 2024 (9 annual anchors)	DOHAC PHN fact sheet (2024) and model-derived construction	The annual calibration series was constructed from the population estimate of 621,404 and the 11.21% population-growth statistic reported in the PHN fact sheet. The implied compound annual growth rate was applied to derive annual anchors across the model's 2016–2024 calibration window, which were then linearly interpolated to produce monthly targets. The series is therefore a model-constructed demographic trajectory rather than a set of independently observed annual population estimates.
Patients receiving community treatment	Stock	people	Jan 2014–Jan 2024 (11 annual anchors)	AIHW analysis of MBS data	Annual counts of people receiving selected Medicare-subsidised psychological services were divided by 12 to obtain monthly-equivalent values and linearly interpolated between anchors. The series was used as a pragmatic proxy for the active psychological-treatment stock rather than as a treatment-admission flow or literal point-in-time census of concurrent caseload. Psychological treatment not represented by the selected MBS claims is not captured.
Note. The 'Type' refers to the model element against which each empirical series was calibrated. AIHW, Australian Institute of Health and Welfare; DDWM PHN, Darling Downs and West Moreton Primary Health Network; DOHAC, Australian Government Department of Health, Disability and Ageing; FTE, full-time equivalent; GP, general practitioner; HWDT, Health Workforce Data Tool; MBS, Medicare Benefits Schedule; NHWDS, National Health Workforce Dataset.					

<insert Table 1 about here>

Calibration and uncertainty analysis

Initial parameter values and calibration ranges were specified using administrative data, official statistics, published evidence and expert judgement. For parameters with observable empirical counterparts, these sources informed their initial values or plausible calibration ranges. Parameters lacking directly observable counterparts were specified as structural assumptions or latent scaling terms and examined, where appropriate, through calibration and uncertainty analysis. Table 2 reports selected parameter values, calibration ranges and evidence bases; the complete inventory is provided in Additional file 3 (Parameter inventory).

Table 2
Selected calibrated structural and pathway parameters

Element	Units	Value	Calibration bounds	Evidence basis and interpretation
Average life expectancy	months	1001.4	850–1080	Official life-expectancy prior; calibrated as an aggregate lifespan rather than an age-structured estimate. Cite [48].
Average time in position	months	70.8	6-120	Contextual rural allied health retention evidence; calibrated. Cite [56].
Average time receiving other care	months	11.4	1–18	Calibrated duration for the aggregate other-care pathway; no direct empirical estimate.
Average time to recruit	months	1.00	1–2	Calibrated workforce-adjustment delay; fitted at the lower bound; not an observed vacancy-filling or onboarding time.
Average time to refer	months	1.27	1–6	Calibrated pathway delay; Better Access evidence measures plan-to-treatment rather than GP referral-processing time. Cite [35].
Average treatment duration	months	2.65	2–12	Calibrated jointly with monthly service intensity; Better Access session-use patterns provide contextual evidence. Cite [35, 73].
Awaiting treatment multiplier on primary care mortality	dmnl	0.773	0.70–0.80	Calibrated multiplier applied to primary-care mortality; expert-derived estimate.
Awaiting treatment multiplier on primary care resolution	dmnl	1.179	1.11–1.20	Calibrated multiplier applied to primary-care resolution; expert-derived estimate.
Birth rate	month ⁻¹	0.001080	0.001073–0.001207	Historical birth-rate prior; calibrated and held constant under conditional BAU. Cite [49].
Care-seeking fractional rate	month ⁻¹	0.0247	0.015–0.025	Calibrated monthly presentation hazard; NSMHW and NMHSPF evidence informed plausibility but was not directly converted into this regional rate. Cite [50, 51].
Eligible referral fraction to mental health services	dmnl	0.602	0.50–0.90	Calibrated pathway allocation; Better Access plan-to-treatment evidence is contextual rather than directly equivalent. Cite [35, 73].
Fraction referred to psychology services	dmnl	0.666	0.50–0.90	Calibrated pathway allocation; the regional psychology referral share was not observed directly; Better Access pathway evidence is contextual. Cite [35].
In-treatment multiplier on awaiting treatment mortality	dmnl	0.681	0.60–0.70	Calibrated multiplier applied to awaiting-treatment mortality; expert-derived estimate.
Medicare service utilisation fraction	dmnl	0.501	0.30–0.70	Calibrated jointly with services per clinical FTE; Medicare activity and national workforce evidence provide contextual scale checks, not a directly observed billing fraction. Cite [7, 47].
Mental ill-health multiplier on base mortality	dmnl	1.990	1.90-2.00	Approximately twofold excess-mortality prior; calibrated near the upper bound and not region-specific. Cite [54, 55].
Mental ill-health resolution rate	month ⁻¹	0.0406	0.020–0.050	Untreated-depression remission evidence informed plausibility; calibrated and generalised to the broader modelled mental ill-health population. Cite [52, 53].
Net migration rate	month ⁻¹	0.00146	0.0010–0.0018	Calibrated jointly with births and mortality to reproduce regional population growth; not a direct migration estimate. Cite [28].
Primary care multiplier on mental ill-health mortality	dmnl	0.830	0.80–0.90	Calibrated multiplier applied to mental ill-health mortality; expert-derived estimate.
Primary care multiplier on mental ill-health resolution	dmnl	1.066	1.01–1.10	Calibrated multiplier applied to the mental ill-health resolution rate; expert-derived estimate.
<i>Note.</i> Values are optimiser-derived estimates within the predefined calibration bounds and are reported to the precision shown. Selected parameters are presented; the supplementary parameter inventory reports the remaining parameters and implementation settings. Mortality multipliers operate sequentially: the mental ill-health multiplier is applied to base mortality, the primary-care multiplier to mental ill-health mortality, the awaiting-treatment multiplier to primary-care mortality, and the in-treatment multiplier to awaiting-treatment mortality. Resolution is similarly chained from the mental ill-health resolution rate to primary-care and then awaiting-treatment resolution. BAU, business as usual; DDWM, Darling Downs and West Moreton; FTE, full-time equivalent; MBS, Medicare Benefits Schedule.				

Element	Units	Value	Calibration bounds	Evidence basis and interpretation
Rate of new mental health episodes	month ⁻¹	0.0173	0.010–0.025	Calibrated monthly onset hazard; NSMHW and NMHSPF epidemiology informed plausibility but was not directly converted into this regional rate. Cite [50, 51].
Returning patients to GP fraction	dmnl	0.692	0.10–0.70	Calibrated pathway-recycling assumption; no directly corresponding regional estimate.
Treatment completion fraction	dmnl	0.889	0.40–1.00	Calibrated post-treatment resolution fraction; not an observed completion, improvement, recovery, or adherence rate.
Services delivered per worker per month	services/FTE/month	67.2	20–80	Calibrated jointly with the Medicare service-utilisation fraction; national Medicare activity and workforce evidence provide contextual scale checks, not a direct services-per-FTE estimate. Cite [7, 47].
Services required per patient per month	services/person/month	3.05	1–4	Calibrated jointly with treatment duration; Better Access utilisation provides contextual evidence on session intensity. Cite [35, 73].
<i>Note.</i> Values are optimiser-derived estimates within the predefined calibration bounds and are reported to the precision shown. Selected parameters are presented; the supplementary parameter inventory reports the remaining parameters and implementation settings. Mortality multipliers operate sequentially: the mental ill-health multiplier is applied to base mortality, the primary-care multiplier to mental ill-health mortality, the awaiting-treatment multiplier to primary-care mortality, and the in-treatment multiplier to awaiting-treatment mortality. Resolution is similarly chained from the mental ill-health resolution rate to primary-care and then awaiting-treatment resolution. BAU, business as usual; DDWM, Darling Downs and West Moreton; FTE, full-time equivalent; MBS, Medicare Benefits Schedule.				

<insert Table 2 about here>

Demographic parameters were checked against regional population growth, national life expectancy and birth statistics^{28,48,49}. Assumptions concerning mental ill-health onset and care-seeking were informed by the National Study of Mental Health and Wellbeing and NMHSPF epidemiology^{50,51}; untreated resolution by evidence on depression remission^{52,53}; and excess mortality by Australian and international evidence^{54,55}. Contemporary rural allied health evidence was used to assess the plausibility of average time in role⁵⁶.

Calibration minimised the variance-weighted sum of mean squared errors across the five observed time series. Each series was weighted by the reciprocal of its observed sample variance to reduce the influence of differences in numerical scale. Parameter estimation used Powell's optimisation method⁵⁷, with a tolerance of 0.001, an initial step size of 1 and a maximum of 50,000 iterations. The final parameter inventory specified ranges for 78 parameters.

Multivariate parameter uncertainty was explored using a Sobol low-discrepancy sequence⁵⁸, with uniform sampling over the specified parameter ranges. The calibration parameters were varied, while initial stocks were held fixed to preserve specified starting conditions. A total of 10x10⁶ candidate runs were generated. Runs with calibration payoff values within 30 units of the optimum were retained. We report the mean of the retained ensemble and 95% uncertainty interval (UI), defined as the 2.5th and 97.5th percentiles. These intervals represent uncertainty across parameter combinations retained under the specified acceptance criterion.

Scenario design: Recruitment ceiling, mental ill-health onset, and the combined scenario

We applied three prospective stress-test scenarios to the calibrated model from January 2030, using BAU as the baseline against which to assess changes in workforce outcomes and system-level indicators. The scenarios imposed: (i) a recruitment ceiling; (ii) a progressively increasing mental ill-health onset multiplier; and (iii) their combination. The two component stress tests and their simultaneous application are found in Additional file 4 (Scenario definitions).

Under the recruitment ceiling scenario, gross workforce recruitment was capped at six FTE per month whenever desired recruitment exceeded this limit, testing whether workforce expansion could keep pace with demand⁷. The ceiling represents a stylised proxy for the combined effects of education, funding, and labour-market constraints on psychology workforce growth. Under the onset-pressure scenario, the onset multiplier remained at baseline until January 2030 (model month 204), after which it increased by 0.1% per month on a compounded basis. Evidence on major disruptions¹⁵ and chronic climate-related stressors^{16–18,59} informed the plausibility of persistent pressure, without calibrating its magnitude. The combined scenario applied both settings unchanged, allowing interactions to emerge endogenously rather than assuming additivity.

All scenarios used the same ordered accepted parameter sets as BAU. We report mean within-run scenario-minus-BAU differences and central 95% UIs. Relative differences divide each mean paired difference by the corresponding BAU mean.

Outcomes of interest

The principal workforce outcome was psychologist clinical FTE. Service and population outcomes included the productivity-adjusted Medicare-subsidised service rate, patient counts for primary mental healthcare and community treatment, total population, and people living with mental ill-health. The aforementioned complementary indicators were used to assess system performance and access (Additional file 1; Key model equations). Waiting and treatment populations were interpreted alongside workforce balance, treatment activity, care-seeking and pathway attrition, rather than in isolation as indicators of access.

Results

A detailed description and explanation of the changes observed across the model under BAU, and the three scenario conditions, is provided in Additional file 5 (Detailed descriptions).

Historical fit and conditional business-as-usual trajectory

The accepted ensemble reproduced the broad historical trajectories of regional population, psychologist clinical FTE, Medicare-subsidised service activity, and the two-patient series, although some short-term fluctuations in observed utilisation were not captured (Fig. 2). Under BAU, population growth increased mental ill-health and treatment demand, while unconstrained recruitment allowed workforce and service capacity to expand. By January 2050, mean psychologist clinical FTE reached approximately 503 [433, 577], supporting 16,908 [14,575, 19,174] Medicare-subsidised services per month. Over the same period, the population living with mental ill-health increased to 174,922 [117,789, 269,113]. This expansion maintained a broadly stable pathway but did not eliminate capacity pressure.

The SDI remained below balance at 0.94, while a model-defined workforce gap of 41.5 clinical FTE persisted in January 2050. Care-seeking prevalence was 10.5%, and psychology pipeline attrition was 48.9%. BAU stability was therefore conditional on recruitment continuing to respond to demand without finite training, funding, or candidate-pool constraints. Remaining workforce, access, and pathway indicators are reported in Table 3.

Table 3

Model performance and phenomenological indicators under BAU and prospective stress-test scenarios in January 2050

Indicator	Unit	BAU	Recruitment ceiling			Compounding onset pressure			Combined scenario		
		Mean [95% UI]	Mean	Paired Δ [95% UI]	Relative Δ vs BAU	Mean	Paired Δ [95% UI]	Relative Δ vs BAU	Mean	Paired Δ [95% UI]	Relative Δ vs BAU
Population, system performance and access											
Population without mental ill-health	people	712,813 [585,714, 841,966]	710,357	-2,456 [-9,855, 0]	0.3% ↓	673,810	-39,003 [-50,649, -29,356]	5.5% ↓	670,662	-42,151 [-57,724, -31,085]	5.9% ↓
Supply-demand indicator	unitless	0.936 [0.822, 0.989]	0.806	-0.130 [-0.363, 0.000]	13.9% ↓	0.929	-0.0069 [-0.0116, -0.0031]	0.7% ↓	0.769	-0.167 [-0.403, -0.006]	17.8% ↓
Care-seeking prevalence	%	10.5 [6.3, 17.6]	9.0	-1.47 [-5.62, 0.00]	14.0% ↓	10.3	-0.14 [-0.33, -0.04]	1.3% ↓	8.6	-1.87 [-5.96, -0.05]	17.9% ↓
Suppressed care-seeking gap	people/month	-73 [-678, 444]	398	+ 470 [0, 2,039]	-	-59	+ 14 [-105, 133]	-	603	+ 676 [-79, 2,520]	-
Suppressed care-seeking fraction	%	-3.4 [-24.8, 10.2]	9.7	+ 13.2 [0.0, 51.4]	-	-2.7	+ 0.76 [0.14, 2.61]	-	13.0	+ 16.4 [0.3, 57.1]	-
Psychology pipeline attrition ratio	%	48.9 [25.3, 74.7]	58.8	+ 9.8 [0.0, 32.6]	20.0% ↑	49.3	+ 0.38 [-0.06, 1.04]	0.8% ↑	61.3	+ 12.4 [0.0, 35.1]	25.3% ↑
Treatment waiting stock	people	1,552 [1,020, 2,266]	1,337	-215 [-987, 94]	13.9% ↓	1,828	+ 276 [157, 436]	17.8% ↑	1,534	-19 [-950, 681]	1.2% ↓
Model-defined workforce gap	clinical FTE	41.5 [7.4, 122.5]	62.9	+ 21.4 [-14.0, 82.2]	51.6% ↑	49.5	+ 8.0 [1.8, 20.5]	19.3% ↑	82.3	+ 40.8 [-8.3, 111.8]	98.1% ↑
Workforce and phenomenological indicators											
Workforce energy	dmnl	0.573 [0.350, 0.860]	0.438	-0.135 [-0.432, 0.000]	23.6% ↓	0.564	-0.0093 [-0.0246, -0.0012]	1.6% ↓	0.402	-0.172 [-0.472, -0.004]	29.9% ↓
Professional passion	dmnl	0.530 [0.425, 0.674]	0.465	-0.064 [-0.251, 0.000]	12.1% ↓	0.525	-0.0043 [-0.0116, -0.0004]	0.8% ↓	0.448	-0.081 [-0.268, -0.001]	15.3% ↓
Service quality	dmnl	0.683 [0.508, 0.934]	0.643	-0.040 [-0.193, 0.000]	5.9% ↓	0.680	-0.00237 [-0.00917, -0.00008]	0.3% ↓	0.634	-0.0484 [-0.2111, -0.0004]	7.1% ↓
Relative turnover intention	dmnl	0.988 [0.847, 1.074]	1.021	+ 0.034 [0.000, 0.161]	3.4% ↑	0.989	+ 0.00187 [0.00011, 0.00776]	0.2% ↑	1.028	+ 0.041 [0.000, 0.181]	4.1% ↑
Adjusted average time in position	dmnl	65.1 [20.8, 119.8]	63.5	-1.56 [-8.95, 0.00]	2.4% ↓	64.9	-0.15 [-0.81, -0.01]	0.2% ↓	62.9	-2.13 [-10.85, -0.03]	3.3% ↓
Societal perception of waiting	dmnl	0.923 [0.511, 1.117]	1.134	+ 0.210 [0.000, 0.752]	22.8% ↑	0.932	+ 0.00904 [0.00260, 0.01722]	1.0% ↑	1.199	+ 0.276 [0.005, 0.896]	29.9% ↑
Perceived relative	dmnl	1.001 [0.966, 1.036]	0.969	-0.033 [-0.133, 0.066]	3.3% ↓	1.000	-0.0015 [-0.0059, 0.0029]	0.1% ↓	0.960	-0.041 [-0.145, 0.063]	4.1% ↓

Note. BAU, business as usual; FTE, full-time equivalent; UI, uncertainty interval. BAU entries are ensemble means with central 95% UIs. Scenario columns report the mean, mean paired difference (scenario minus matched BAU run) with its central 95% UI, and the mean paired difference relative to the BAU mean. For percentage indicators, paired differences are percentage points and relative differences are percentage changes. Relative differences are omitted for the suppressed care-seeking gap and fraction because their negative BAU references make ratios misleading. Figures 2–4 show the principal outcomes for BAU and the two individual stress tests; the combined scenario outcomes are reported in Results. Table 5 reports the remaining 16 indicators under all four conditions. Negative suppressed-care-seeking values indicate presentations above normal expectation. Suppression responds to delayed societal perception of waiting, not directly to SDI; a lower waiting stock therefore need not indicate improved access when care-seeking falls or pathway attrition rises.

Indicator	Unit	BAU	Recruitment ceiling			Compounding onset pressure			Combined scenario		
		Mean [95% UI]	Mean	Paired Δ [95% UI]	Relative Δ vs BAU	Mean	Paired Δ [95% UI]	Relative Δ vs BAU	Mean	Paired Δ [95% UI]	Relative Δ vs BAU
Population, system performance and access											
system performance		1.038]		0.000]			-0.0003]			-0.001]	
Perceived relative wait time	dmnl	0.923 [0.511, 1.116]	1.150	+ 0.227 [0.000, 0.780]	24.6% ↑	0.932	+ 0.0090 [0.0026, 0.0174]	1.0% ↑	1.224	+ 0.301 [0.006, 0.948]	32.6% ↑
Note. BAU, business as usual; FTE, full-time equivalent; UI, uncertainty interval. BAU entries are ensemble means with central 95% UIs. Scenario columns report the mean, mean paired difference (scenario minus matched BAU run) with its central 95% UI, and the mean paired difference relative to the BAU mean. For percentage indicators, paired differences are percentage points and relative differences are percentage changes. Relative differences are omitted for the suppressed care-seeking gap and fraction because their negative BAU references make ratios misleading. Figures 2–4 show the principal outcomes for BAU and the two individual stress tests; the combined scenario outcomes are reported in Results. Table 5 reports the remaining 16 indicators under all four conditions. Negative suppressed-care-seeking values indicate presentations above normal expectation. Suppression responds to delayed societal perception of waiting, not directly to SDI; a lower waiting stock therefore need not indicate improved access when care-seeking falls or pathway attrition rises.											

<insert Fig. 2 about here>

<insert Table 3 about here>

Constrained recruitment

The recruitment ceiling became binding in 77 of the 101 (76.2%) matched simulations; the remaining trajectories were unchanged, as indicated recruitment never exceeded six clinical FTE per month. By January 2050, mean psychologist clinical FTE was approximately 163 [-420, 0] lower than BAU (-32.5%), while Medicare-subsidised service activity was lower by 4,818 [-12,533, 0] services per month (-28.5%). Fewer people received community psychological treatment, and the population living with mental ill-health was correspondingly larger (Fig. 3). The inclusion of zero in several uncertainty intervals reflects variation in whether the ceiling became binding across accepted parameter combinations.

<insert Fig. 3 about here>

The visible treatment queue nevertheless fell by 13.9%. This reduction coincided with a 13.9% lower SDI, 14.0% lower care-seeking prevalence, a 13.2 percentage-point increase in suppressed care-seeking, and a 9.8 percentage-point increase in psychology pathway attrition. The model-defined workforce gap was also 51.6% larger than under BAU (Table 3). The smaller queue therefore reflected less need entering and remaining within the observable pathway, rather than greater capacity to provide treatment.

Modelled workforce conditions moved in the same adverse direction. Workforce energy, professional passion, service quality and perceived system performance were lower than BAU, whereas turnover intention and delayed waiting-perception measures were higher (Table 3).

Compounding mental ill-health onset scenario

Under progressively compounding onset pressure, increasing need stimulated workforce and service expansion, with recruitment remaining unconstrained. By January 2050, psychologist clinical FTE was approximately 78 [56, 101] higher than BAU (+ 15.5%), while Medicare-subsidised service activity increased by 2,694 [2,104, 3,272] services per month (+ 15.9%). However, the population living with mental ill-health increased by 32,084 [24,123, 42,586] people (+ 18.3%), exceeding the relative expansion in workforce and service capacity (Fig. 4).

<insert Fig. 4 about here>

Unlike the recruitment-ceiling scenario, increasing onset pressure produced more visible as well as underlying demand. The treatment waiting stock was 17.8% higher, while the model-defined workforce gap increased by 19.3%. The SDI declined by only 0.7%, and changes in care-seeking, pathway attrition, and workforce conditions remained comparatively small (Table 3). Unconstrained recruitment therefore absorbed much of the additional pressure without preventing growth in the absolute population burden or treatment queue.

Combined recruitment ceiling and onset pressure scenario

When onset pressure increased under constrained recruitment, workforce expansion did not keep pace with the additional demand. By January 2050, mean psychologist clinical FTE was approximately 147 [-421, 84] lower than BAU (-29.2%), while Medicare-subsidised service activity was lower by 3,961 [-12,543, 2,917] services per month (-23.4%). Although the uncertainty intervals included increases and decreases across accepted runs, the population living with mental ill-health was consistently larger, with a mean paired difference of 38,154 [24,853, 55,188] people (+ 21.8%).

Despite this greater burden and constrained capacity, the treatment waiting stock remained close to its BAU level, with a mean reduction of 1.2%. The relative stability of the queue coincided with a 17.8% lower SDI, 17.9% lower care-seeking prevalence, a 16.4 percentage-point increase in suppressed

care-seeking, and 12.4 percentage-point increase in pathway attrition. Patients receiving primary mental healthcare were slightly higher on average, although the paired UI included both decreases and increases (Table 3). Within the model, primary-care activity could therefore remain stable or increase while fewer people reached or remained in community psychological treatment.

The combined scenario produced the clearest divergence between visible queues and underlying access. The waiting stock remained close to BAU (1.2% lower), despite a 98.1% larger workforce gap, illustrating why the queue alone did not represent unmet need. Rather, suppressed care-seeking and increased pathway attrition reduced the proportion of need expressed and retained within the observable treatment pathway. The accompanying decline in modelled workforce conditions was also greater than under either pressure in isolation (Table 3).

Discussion

This study builds on previous applications of system dynamics to human resources for health planning internationally^{2,60,61} and Australian mental health services^{9,62–66}, and contributes to the growing literature on population mental health modelling, which emphasises transparent model specification, validation and reporting^{42,67}. By integrating regional workforce capacity, service access and endogenous behavioural adaptation within an empirically calibrated model, it responds to calls for more integrated and dynamic approaches to workforce planning^{25,26}. The public availability of the complete simulation model via iSee Exchange™ further supports transparency, reproducibility and knowledge translation by enabling users to inspect model structure, test assumptions and explore the implications of alternative policy scenarios³⁴.

The principal finding is that constrained workforce capacity need not produce a larger treatment queue. Under the recruitment ceiling scenario, the widening gap between required and available clinical FTE constrained service capacity relative to demand, increasing actual and perceived waiting times. Longer waits increased attrition before treatment initiation and eroded societal perceptions of the mental health system, reducing the likelihood of seeking primary mental healthcare. The waiting stock therefore declined or remained near BAU despite worsening workforce balance and treatment access, thereby making unmet need less visible through conventional service and waiting-list indicators. The divergence was greatest under combined pressure, when a near-BAU queue coexisted with a larger population living with mental ill-health and poorer workforce balance. The model thus illustrates how endogenous feedback processes can produce a deceptively stable treatment queue despite deteriorating access to care.

Conditional stability and complementarity with national projections

Under BAU, population growth increased treatment demand while uncapped recruitment expanded workforce and services, maintaining broadly stable access indicators (Table 3). This stability depended on recruitment responding to the workforce gap without explicit constraints on training capacity, candidate availability, funding or labour-market conditions. BAU therefore illustrates the workforce expansion required to maintain the modelled pathway under these assumptions, rather than evidence that this workforce is currently available or will necessarily be supplied.

The national Psychology Supply and Demand Study⁷ instead projects future workforce supply using historically observed entry, exit, re-entry, FTE participation and interstate mobility. The approaches are complementary. Regional BAU identifies the workforce expansion implied by assumptions baked into the model and provides a counterfactual for restricted expansion, while the national study assesses future supply. BAU should therefore not be interpreted as contradicting national projections of widening psychology workforce shortfalls⁷.

How workforce constraints conceal unmet need

Activating the recruitment ceiling, with onset pressure held at BAU, reduced both the treatment queue and the number of people receiving community psychological treatment. By January 2050, psychologist clinical FTE and service activity were also lower than BAU. Care-seeking prevalence and the SDI fell, while pathway attrition and suppressed care-seeking increased. Reduced capacity therefore changed both care provision and how much need became visible to services. Fewer people entered or progressed through the care pathway, while unmet need remained outside treatment. These dynamics have implications for the timeliness and accessibility of psychological treatment under Australia's Better Access initiative^{1,68–73}. Realised service use may therefore reflect only part of population need¹.

Under the recruitment ceiling, modelled workforce and service conditions also deteriorated. Workforce energy, professional passion and service quality were 23.6%, 12.1% and 5.9% lower than BAU, while turnover intention and perceived waiting time were 3.4% and 22.8% higher. These findings illustrate that workforce constraints can propagate through behavioural and experiential pathways, further affecting service capacity and access in ways not apparent from FTE, service volume or epidemiological measures alone. The recruitment ceiling should therefore be interpreted as a test of finite workforce expansion capacity; six FTE per month is neither a DDWM estimate nor a recommended policy threshold⁷.

Increasing need under unconstrained recruitment

Under the onset-pressure scenario, mental ill-health onset increased progressively while recruitment remained uncapped. Psychologist clinical FTE and service activity increased by approximately 16% relative to BAU by January 2050 as increasing need stimulated recruitment. Yet the population living with mental ill-health, treatment waiting stock and workforce gap remained substantially above BAU. Continued recruitment partially offset increasing demand, moderating adverse changes in access, care-seeking, pathway attrition and workforce conditions. The practical implication is that sustained growth in need requires continuing recruitment capacity, even when workforce and service numbers are rising.

Where climate-related or other chronic stressors sustain rising need^{16–18,59}, training and workforce-entry pathways must be capable of supporting sustained workforce expansion. Higher workforce and service activity alone do not demonstrate adequate care when population mental health burden and waiting also grow. This scenario is an illustrative capacity stress test, rather than a forecast of any specific pandemic, climate exposure or disaster^{15,16}.

When constrained capacity meets compounding need

Under the combined scenario, the recruitment ceiling and compounding mental ill-health onset pressure operated simultaneously. Gross workforce recruitment remained restricted to six FTE per month. Workforce and service responses varied across the retained parameter ensemble, but the 95% uncertainty interval for paired differences in the population living with mental ill-health lay entirely above zero relative to BAU. Primary mental healthcare activity could remain stable or increase as patients with unresolved needs returned to general practice, even as downstream psychological treatment access deteriorated. Thus, a stable treatment queue could coexist with greater mental ill-health burden and poorer treatment access. Suppressed care-seeking and exits without resolution could mask unmet need in conventional service and waiting-list indicators. These outcomes arose from interacting pressures within the model, rather than from assuming that the two stressors had additive effects.

Implications for complex systems modelling in human resources for health

These findings support workforce modelling that explicitly represents behavioural adaptation alongside workforce, service and population dynamics. Operationalising qualitative constructs within calibrated quantitative structures^{21,22} extends earlier modelling of workload, burnout and care quality⁷⁴ by linking these mechanisms with workforce supply and service access. Here, perceptions, energy, passion, service quality and turnover intention shaped workforce capacity, care-seeking and treatment access through interacting feedback processes. This demonstrates how routinely collected administrative data can be integrated with practitioner knowledge to represent behavioural mechanisms that are difficult to observe directly, while maintaining transparency around underlying assumptions.

Consistent with locally responsive, whole-of-system workforce planning²⁶, workforce FTE, service volumes and waiting lists should be interpreted alongside care-seeking, suppressed presentation, pathway attrition, unresolved exits and repeated primary care contact. Considering these indicators together can reveal deteriorating access that might otherwise be masked by apparently stable workforce and service measures. Modelled energy, passion, service quality and turnover intention provide exploratory indicators of workforce strain and adaptation, rather than independently validated psychometric measures.

Methodologically, this regional modelling study offers a modelling framework that could be adapted and extended across settings and scales. Its comparison with the Australian Psychology Supply and Demand Study⁷ is methodological rather than numerical. The national study uses microsimulation and regression to assess whether a workforce pipeline will meet aggregate demand, whereas the present model examines behavioural adaptation and endogenous feedback processes within a defined regional pathway. These approaches could ultimately be integrated. National workforce pipeline components such as training, graduation, registration, workforce entry and exit, re-entry, mobility, clinical FTE and movement between health and non-health settings could be incorporated while retaining feedback from demand, waiting, care-seeking, perceived system conditions, productivity and turnover. Application in other settings would require local validation of relationships and parameter values, transparent model specification, uncertainty analysis and broader stakeholder review.

Study limitations

Several limitations warrant attention. The aggregate model does not distinguish age, diagnosis, severity or geographic distribution within the large DDWM catchment. General and clinical psychologists are combined, and Medicare claims capture only part of community psychological care. Treatment duration and intensity are represented as averages, while provider fees, Medicare rebates, patient gap payments, public and acute services, PHN-commissioned care, disability supports, fully private care and workforce skill mix are not modelled as distinct systems.

No longitudinal point-in-time caseload series was available. Annual Medicare counts of people receiving relevant services were converted to monthly-equivalent trajectories and used as pragmatic proxies for active primary care and psychological treatment stocks, rather than observed censuses of concurrent caseload.

Observed utilisation temporarily increased during the late 2010s and early 2020s in several calibration series (Figs. 2–4), whereas the model reproduced the broader historical trajectory. Better Access telehealth rebates for rural and remote patients commenced on 1 November 2017⁷⁵; national MBS telehealth was introduced in March 2020 and made permanent from 2022⁷⁶; and eligible patients could access up to 20 individual Better Access sessions from 9 October 2020 to 31 December 2022⁷⁷. Because these step changes were not represented explicitly, the model should not be expected to reproduce every short-term utilisation fluctuation.

Most importantly, BAU assumes that indicated recruitment can occur without finite training, candidate, or budget constraints. The three scenario conditions are evidence-informed stress tests, not calibrated policy evaluations or event forecasts. Results remain conditional on the recruitment threshold, onset activation date, monthly compounding rate, and duration. Future work should test the model under a wider range of conditions and parameter settings.

Conclusion

Using an empirically calibrated system dynamics model of community psychological treatment in southern Queensland, Australia, we examined how workforce capacity, increasing mental ill-health and behavioural adaptation influence treatment access to 2050. Under BAU, broadly stable access depended on recruitment keeping pace with demand without explicit recruitment constraints. Capping recruitment reduced treatment activity and care-seeking, increased pathway attrition and worsened workforce conditions, even as the treatment queue reduced. Increasing mental ill-health onset expanded workforce and service activity under uncapped recruitment, yet population need and treatment waiting continued to rise. Combined, these pressures produced the greatest deterioration in mental ill-health burden and treatment access, with a near-BAU queue concealing growing unmet need.

These findings demonstrate that workforce numbers, service volumes and waiting lists alone can provide an incomplete picture of mental healthcare access. By explicitly integrating behavioural and experiential feedback within an empirically calibrated simulation model, this study highlights the importance of interpreting workforce capacity alongside care-seeking, pathway attrition and unresolved need. Such approaches could support more integrated, whole-of-system workforce planning, from regional service delivery to national and international workforce policy.

Abbreviations

BAU: business-as-usual

DDWM: Darling Downs and West Moreton

NDIS: National Disability Insurance Scheme

NMHSPF: National Mental Health Service Planning Framework

PHN: Primary Health Network

SDI: supply-demand indicator

UI: uncertainty interval

Declarations

Ethics approval and consent to participate

Ethics approval and participant consent procedures are described in the Methods section.

Consent for publication

Not applicable

Availability of data and materials

The public data sources used for model calibration are identified in Table 1. Full model equations, the parameter inventory, and response-function documentation are provided in Additional files 1-3. Simulation outputs and SDgraphing analysis files used to reproduce the reported tables and figures are available from the corresponding author upon reasonable request. The complete executable simulation model is publicly available through the iSee Exchange repository³⁴, enabling readers to inspect model structure and undertake additional scenario analyses.

Competing interests

AH is the founder of Systems Science Lab and developer of SDgraphing, the software used in this study for sensitivity ensemble generation. SDgraphing is available free of charge, and AH receives no fees from its use. CT was a member of the team that conducted the Better Access Evaluation, which was funded by the Australian Government Department of Health, Disability and Ageing.

Funding

This work was supported by an Australian Research Council DECRA Award held by AH (DE240100095). JKR's contribution was partly supported by a project grant from L. Meltzers Universitetsstiftelse (application ID 33584).

Author contributions

AH conceived the study, conducted the analyses, interpreted the results, prepared the visualisations, and wrote the original manuscript. AH and JKR both developed the model, with AH taking primary responsibility for model construction and JKR contributing to refinement of model structure and assumptions. CT, EW, FC and TH contributed domain expertise in mental health service delivery and systems that informed model development. JKR contributed to interpretation of the results and reviewed and edited the manuscript. CT, EW, FC, BK and TH reviewed and edited the manuscript. All authors read and approved the final manuscript.

Use of generative artificial intelligence and AI-assisted technologies

During manuscript preparation, the authors drafted the original manuscript and used AI tools for language refinement, cross-checking mathematical descriptions against the Stella equation codebase, and formatting and verification of tables. All AI-assisted revisions were critically reviewed and verified by the authors, who made all substantive intellectual decisions and accept full responsibility for the accuracy, integrity, and conclusions of the work. Stella Architect Professional now includes an AI Assistant that supports causal loop diagram and simulation (stock-and-flow) model development, analysis, explanation, and documentation. The model reported in this study was conceived, developed, and parameterised prior to the July 2025 release of Stella 4.0, which introduced AI-supported model development. Following model construction, Stella Architect Professional's AI-assisted functionality was to support variable documentation.

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Figures

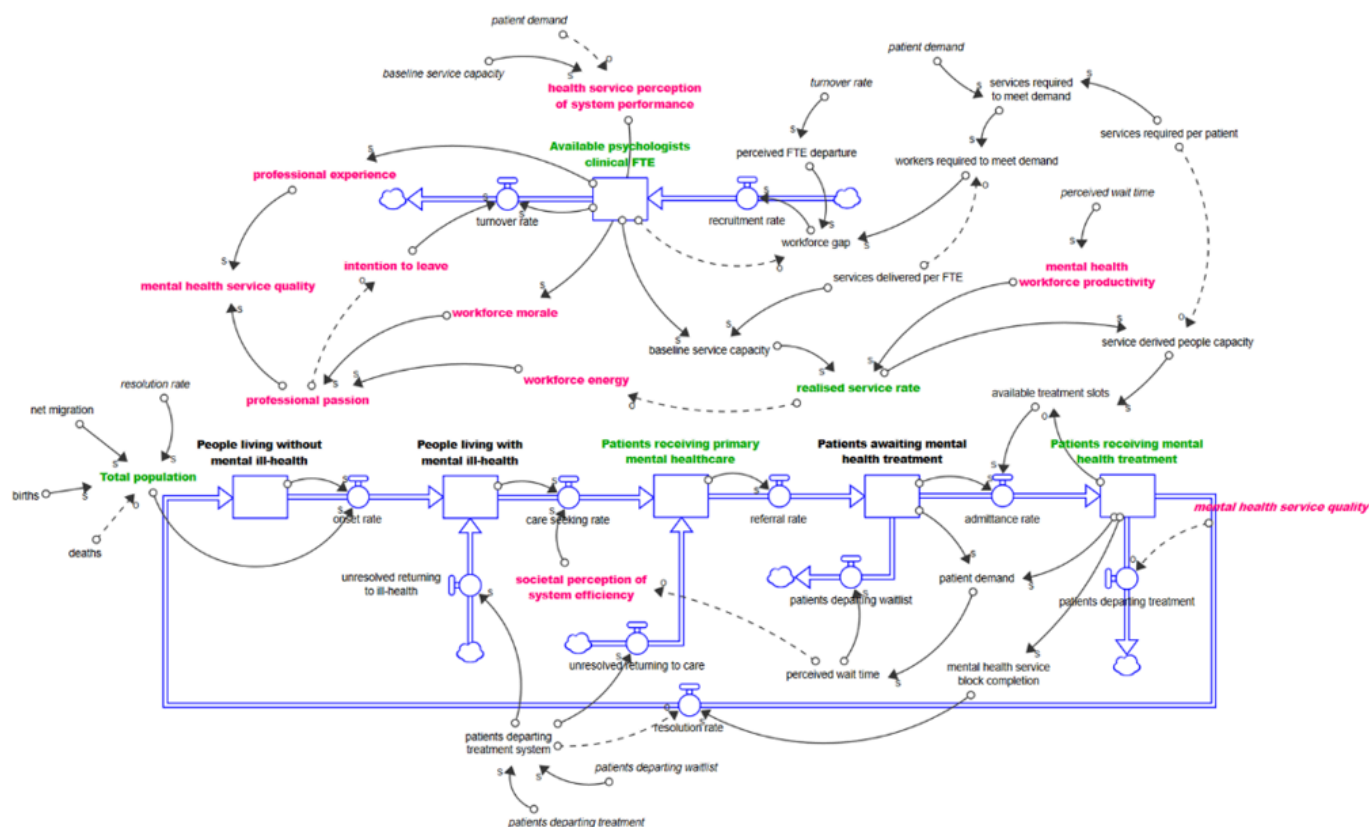


Figure 1

Conceptual causal loop diagram of the multi-sector system dynamics model

Note. S and O denote same and opposite direction causal relationships, respectively, all else being equal. Rectangles represent stocks and double-lined arrows represent flows. Green variables denote quantities calibrated against empirical time series; pink variables denote qualitative or “soft” constructs. Italicised names indicate shadow variables included solely for readability due to feedback loop complexity. The complete system dynamics model contains 363 variables across seven sectors: 18 stocks, 38 flows and 307 converters. *System narrative:* Population need progresses through mental ill-health onset, primary-care presentation, referral, waiting and psychological treatment, followed by resolution, return or pathway departure. Clinical FTE, services delivered per FTE and productivity determine service capacity and available treatment slots. Demand and service requirements determine the required workforce and resulting workforce gap, which influences recruitment. Perceptions of health service performance shapes workforce morale. Perceived waiting affects workforce productivity and societal perceptions, which influence care-seeking; productivity affects workforce energy; morale and energy jointly shape professional passion, which affects intention to leave; and passion interacts multiplicatively with professional experience to determine service quality. These mechanisms feedback through recruitment, turnover, admission, waiting-list departure, treatment completion and treatment departure.

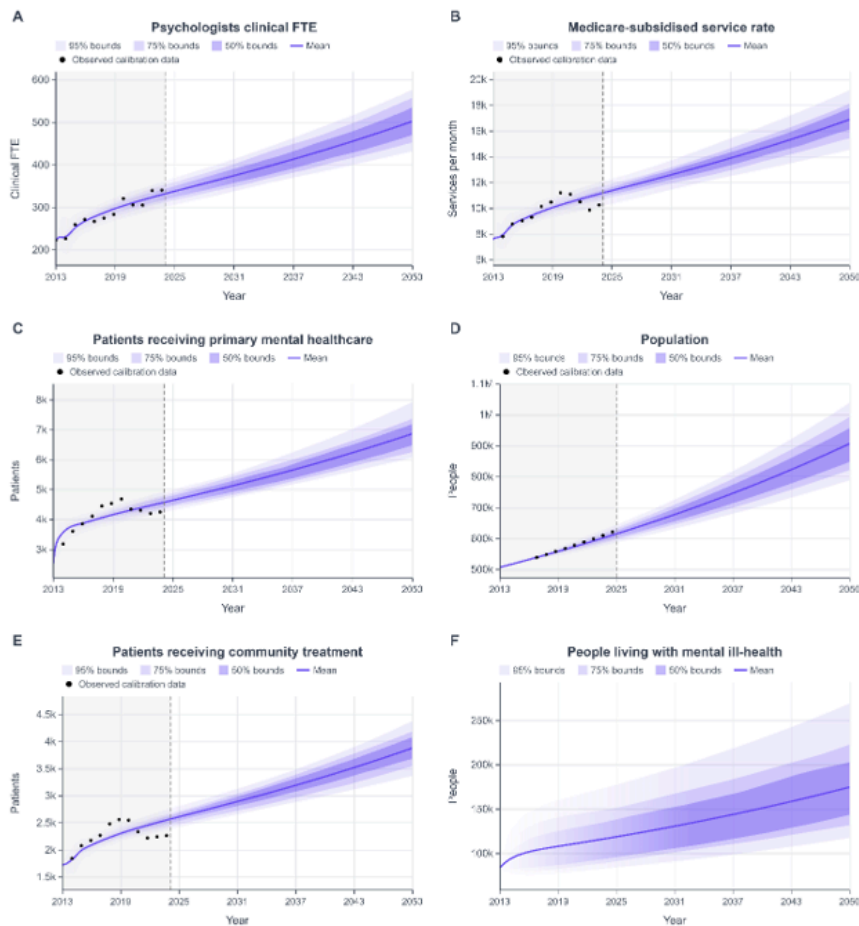


Figure 2

Business-as-usual ensemble trajectories, January 2013 - January 2050

Note. Panels show (A) psychologists clinical FTE; (B) Medicare-subsidised service rate; (C) patients receiving primary mental healthcare; (D) population; (E) patients receiving community treatment; and (F) people living with mental ill-health. Solid lines show the mean across the 101 accepted parameter sets, and the nested shaded regions show the central 50%, 75% and 95% accepted-ensemble intervals. Black circles denote observed historical calibration data where available. The vertical dashed line in Panels A-E marks the end of the historical calibration period and the beginning of the conditional projection period. Under BAU, demand-responsive recruitment remained uncapped, and the mental ill-health onset multiplier remained at baseline. FTE, full-time equivalent.

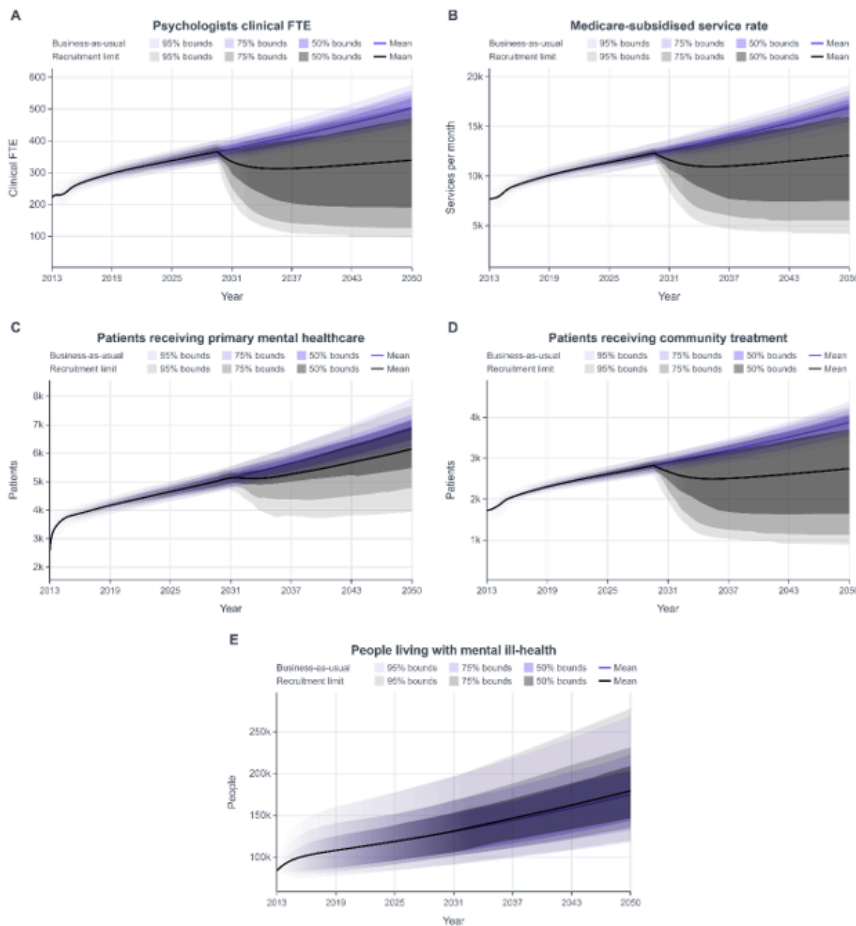


Figure 3

Comparison between BAU and recruitment-ceiling ensemble trajectories, January 2013 - January 2050

Note. Panels show (A) psychologists clinical FTE; (B) Medicare-subsidised service rate; (C) patients receiving primary mental healthcare; (D) patients receiving community treatment; and (E) people living with mental ill-health. Solid lines show the ensemble means, and the nested shaded regions show the central 50%, 75% and 95% intervals across the same ordered 101 accepted parameter sets. The recruitment ceiling was enabled after January 2030 and limited gross psychologist recruitment to six FTE per month when desired recruitment exceeded that threshold. The paired BAU and recruitment-ceiling trajectories were identical through January 2030; the ceiling did not bind in every accepted run; some scenario trajectories remained identical to their paired BAU trajectories. The shaded regions describe the distributions of the trajectories under each condition rather than the paired scenario-minus-BAU effect intervals reported in the text and Table 5. BAU, business as usual; FTE, full-time equivalent.

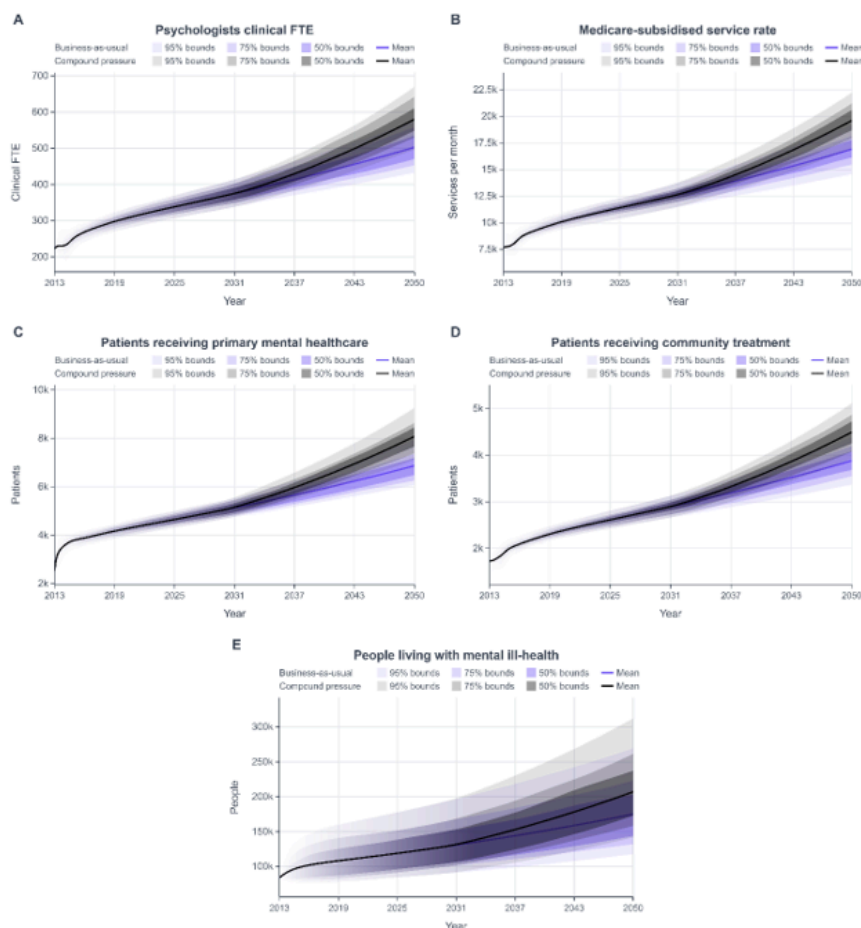


Figure 4

Comparison between BAU and persistent pressure ensemble trajectories, January 2013 - January 2050

Note. Panels show (A) psychologist clinical FTE; (B) Medicare-subsidised service rate; (C) patients receiving primary mental healthcare; (D) patients receiving community treatment; and (E) people living with mental ill-health. Solid lines show ensemble means, and the nested shaded regions show the central 50%, 75% and 95% intervals across the same ordered 101 accepted parameter sets. Beginning in January 2030, the progressively compounding onset-pressure scenario increased the mental ill-health onset multiplier by 0.1% per month. All other model equations and accepted parameter sets were retained. The scenario represents a hypothetical, progressively compounding persistent demand stress on mental health onset. The shaded regions describe the distributions of trajectories under each condition rather than the paired scenario-minus-BAU effect intervals reported in the text and Table 5. BAU, business as usual; FTE, full-time equivalent.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Additionalfile1Keymodelequations.docx](#)
- [Additionalfile4Scenariodefinitions.docx](#)
- [Additionalfile5Detaileddescriptionandexplanation.docx](#)
- [Additionalfile3Parameterinventory.docx](#)
- [Additionalfile2Fullmodelequationsanddocumentation.docx](#)