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Balancing patient choice and health system capacity: a system dynamics model of dialysis in Thailand

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Abstract

Background As universal health coverage schemes mature, governments often seek to improve patient choice, whilst ensuring that services are appropriate, high-quality, and financially sustainable, especially for high-cost interventions like dialysis. Policy levers to manage supply and demand for services have shown mixed results across contexts, highlighting the complex interactions and feedback effects that shape health system behaviours. Following a policy change in Thailand aiming to improve patient choice for dialysis, we developed a system dynamics model of dialysis demand and supply, to explore the impact of proposed policies on dialysis services whilst accounting for considerable uncertainty in how these policies may work.

Methods Model structure was based on a causal loop diagram developed in consultation with stakeholders and iteratively refined through testing, calibration, and validation. The resulting model projected profile of dialysis patients over a 10-year time horizon (2025–2034) under the current policy alongside policy interventions proposed by a working group under the National Health Security Office. We conducted structural and parameter uncertainty analysis to account for uncertainties in the base model and in the mechanisms of action of proposed policy interventions.

Results The model projected that more than one-third of new dialysis patients would inappropriately initiate dialysis under the current policy. None of the proposed policy interventions, either alone or in combination, achieved the defined policy target of 50% new dialysis patients on peritoneal dialysis within 3 years, with a maximum of 45% achieved from combining policies. Performance of all policies decreased over time unless the policy was able to progressively reduce financial incentives paid by private dialysis centres to physicians.

Conclusions Regulating financial incentives in the Thai health system offered the greatest potential to reduce inappropriate dialysis initiation and increase peritoneal dialysis uptake. The system dynamics model showed that coupling policies with complementary mechanisms could address key uncertainties and amplify their impact. We suggest that policymakers incorporate quality of care and time-dependent performance into policy goals to achieve sustainable improvements. Our findings highlight the value of a systems approach to account for unintended consequences of well-intended policy interventions, resulting from delayed responses across organisational boundaries.

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Keywords System dynamics, Peritoneal dialysis, Financial incentives, Health systems, Supply and demand, Dialysis, Kidney disease

Background

Universal Health Coverage (UHC) either implicitly or explicitly involves rationing access to health services [1]. Explicit measures include definition of a benefit package (i.e. which services are provided, under which eligibility criteria, and with which level of co-payment) based on available financial and human resources, whereas implicit rationing occurs when the benefit package is either undefined or more generous than available resources allow [2]. This is particularly true of high-cost interventions such as dialysis. In the absence of kidney transplant, dialysis is the only available treatment to keep patients with kidney failure alive, but it places a disproportionate strain on the budget and workforce of the health system, with middle-income countries in Asia spending over 5% of the healthcare budget on dialysis provision for less than 0.5% of the population [3].

On the path to UHC, governments can build towards universal coverage by progressively increasing the proportion of patients with access to affordable and high-quality services [1, 4]. Policies may initially entail strict eligibility criteria and limited patient choice [2, 3], but over time improvements in system capacity and health system resources may justify preference-sensitive care, in which patient choice increasingly determines the services provided [5]. Within the context of dialysis, this may mean shifting from policies that dictate the type of dialysis patients can access towards policies allowing patient choice between services.

The transition from essential care to patient choice needs to be carefully managed, particularly in systems with heavy reliance on private service providers. Strict conditions to access health services implicitly regulate the private sector [6], but increased patient choice requires strong regulatory frameworks to address information asymmetry between patients and healthcare providers [7]. In the case of dialysis, such regulation needs to effectively manage diverse stakeholder interests, including patient demand for optimal treatment with limited knowledge, resource constraints of public hospitals, private centre incentives to maximise profits, and the tension between good clinical practice and financial incentives for healthcare professionals. Such regulatory structures are, however, often weaker in low-income and middle-income countries (LMICs) [7]. Even in high-income countries with well-developed governance systems, patient choice often does not explain variations in care between settings, which may instead be explained by supply-side factors, including financing mechanisms (e.g. fee-for-service or per capita payments) and geographic location of services [5, 8].

A range of policy levers exist to regulate demand and supply, such that incentives within the system align with health system goals. Such levers may include varying provider payment mechanisms, setting targets, putting in place transparent reporting systems, developing clinical practice guidelines, or introducing decision aids for patients [8]. Yet the performance of the same policy levers can be highly variable, even in supposedly similar contexts. Taking the example of dialysis, there is a growing body of evidence that fee-for-service payments can result in unnecessary healthcare visits and treatments, similar to other hospital-based services [9, 10]. However, payment mechanism reforms show heterogeneous performance that is difficult to explain and appears to be highly context-specific [9–14]. Similarly, educational services have successfully increased uptake of home-based dialysis services in countries with public sector service provision, but performance remains mixed in other settings [15].

Given this complexity and the context-specific nature of policy performance, a system-level perspective can disentangle the feedback loops and emergent behaviours that shape policy outcomes. System dynamics (SD) is a methodology for understanding and analysing complex systems by mapping and simulating the feedback loops and time delays that affect system behaviour, thereby informing strategic or high-level policy decisions [16]. There is growing application of SD modelling in healthcare, with studies on patient flow, public health interventions, medicine supply, infectious diseases, and workforce demand [17, 18]. Healthcare service provision is well suited for SD modelling as it exhibits a number of features of a complex adaptive system, including feedback between supply and demand, delayed and unintended consequences of interventions that targeted one part of the system in isolation, and system-wide adaptation driven by stakeholder reactions to change (for example, service providers and patients). Within the context of UHC, SD is particularly useful to show how organisational design and financing mechanisms impact access and quality of healthcare services [19].

In this study, we use SD modelling as an exploratory tool to understand the impact of policy options to manage supply and demand of dialysis services in Thailand. SD is particularly well suited for analysing Thailand's dialysis policy transition because it captures important feedback loops between financial incentives, provider behaviour, and patient choice that evolve over time, alongside delays between policy and system adaptation. The Thai government had introduced a “PD-first” policy in 2008, which provided universal coverage of dialysis for kidney failure patients, with strict criteria determining the type of dialysis received [20]. This policy had been revised in 2022 to allow patient choice between peritoneal dialysis (PD, administered daily by the patient at home) or haemodialysis (HD, provided by three times a week by trained nurses at health facilities). Initial evaluation of the 2022 policy had suggested strong presence of supply-sensitive care, driven by financial incentives for various actors within the system as opposed to true patient choice, which was leading to high programme costs and low quality of dialysis [21].

To address these concerns, an ad hoc working group was established to propose a set of policy interventions in 2024 by the National Health Security Office (NHSO, the authority overseeing the largest public health insurance scheme in Thailand). Based on prior research, the working group had defined a set of policy goals to reduce inappropriate initiation of dialysis, to encourage uptake of PD, and to manage budget expenditures without compromising on quality of care.

In this study, we illustrate the application of SD as an exploratory tool to test how different policies to manage supply and demand may perform in a specific context. We aimed to identify which of a set of proposed policies could reach the defined policy goals and key sources of uncertainty that could determine policy success. Our two research objectives, based on targets and timeframes established by policymakers [21], were as follows: (1) to identify which policy options could achieve the goal of 50% new dialysis patients selecting PD within 3 years and (2) to characterise the impact of these policies on total number of dialysis patients and dialysis-related mortality over a 10-year period.

Methods

Model context

The setting for the study was the Universal Coverage Scheme (UCS) in Thailand, which is the public health insurance scheme covering the majority of the population [22]. Most kidney failure patients in Thailand are treated by dialysis, due to limited capacity for kidney transplant [23, 24]. Not all patients with kidney failure receive dialysis or transplant: selected patients, particularly those with short life expectancy, may have better quality of life with comprehensive conservative care (CCC) than dialysis [25, 26]. Under CCC, patients receive holistic, person-centred care to delay disease progression and manage symptoms [27].

Under UCS, PD is only provided by public hospitals whereas HD is provided by both public and private centres, with the majority of patients receiving HD in private centres [28]. PD and HD are both free at point of care for patients, as mandated for all services provided under UCS [29]. Although PD is administered by the patients themselves, PD nurses provide regular training and follow-up, with evidence that more patients per nurse can increase rates of peritonitis, one of the main complications for PD [30]. In Thailand, data suggest that more than half of PD patients require assisted PD from caregivers (mostly family members), although assisted PD is not officially reimbursed [31]. Neither type of dialysis is appropriate for all patients: PD requires a functioning peritoneal membrane (which degrades over time), whereas HD is not suitable for patients with cardiac failure, for example [32]. In 2007, Thailand opted for PD as first-line therapy because it was cheaper than HD, required fewer trained healthcare staff, and could be performed by patients at home with minimal healthcare infrastructure [33].

Prior to initiation of dialysis, PD patients require PD catheter insertion and HD patients require a vascular access operation, both of which are reimbursed under UCS. Vascular access for HD may be long-term or temporary, with temporary vascular access associated with higher risk of complications and shorter timeframe until a subsequent vascular access operation is required [34, 35].

Dialysis providers (i.e. hospitals or private HD centres) are reimbursed by fee-for-service, with a higher reimbursement rate for HD. In Thailand, there is limited regulation of how service providers spend the fee-for-service, with many private providers paying a “doctor fee” to nephrologists to encourage patient referral [36]. The doctor fee is paid to each referring nephrologist per dialysis session and is estimated to account for approximately 10–17% of NHSO reimbursement for dialysis services [21]. Complications arising from dialysis are covered under a separate budget line.

We developed a SD model to evaluate the impact of proposed policies on the dialysis system, according to the goals set by the 2024 ad hoc working group on kidney replacement therapy (KRT). We selected a SD model due to the presence of feedback mechanisms between supply and demand, as well as delays between cause and effect. For instance, we had evidence that rising demand for HD led to the opening of new private HD centres (a delayed process), whilst those centres then stimulate further demand by offering doctors financial incentives for patient referral.

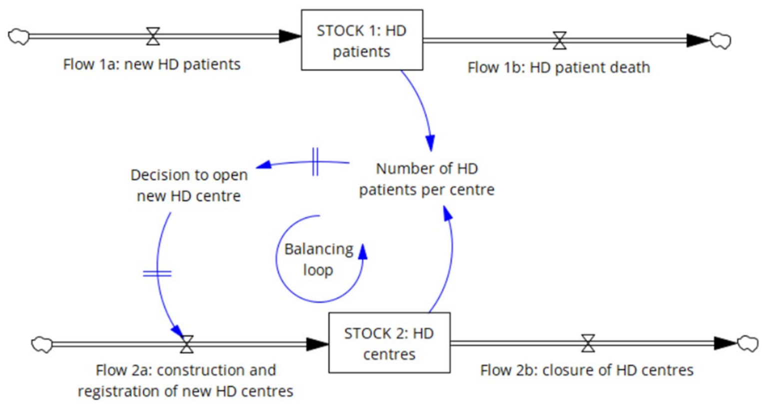

Fig. 1 Illustration of a simple system dynamics (SD) model. The rectangular boxes are stocks, representing number of haemodialysis (HD) patients and centres, respectively. The double arrows represent flows that increase or decrease the stocks. The blue arrows represent a balancing feedback loop, characterised by delays (blue arrows with a double line). HD, haemodialysis

System dynamics modelling

In SD, the behaviour of organisational or social systems is conceptualised as a series of accumulations influenced by feedback mechanisms within the system [37]. An illustration of SD model structure is shown in Fig. 1. Accumulations are represented as stocks, which can be increased or decreased by flows [38]. In Fig. 1, number of HD patients is a stock that increases according to incident HD patient inflow and decreases with HD patient death outflow. These stocks interact through feedback loops, some of which are reinforcing (positive feedback) and can accelerate growth, whilst others are balancing (negative feedback) and constrain system expansion once resource limitations are reached [39]. The example in Fig. 1 illustrates how new centres may be built to respond to unmet demand for HD, which in turn reduces unmet demand, slowing further construction of HD centres through a balancing loop. Stocks are sources of delay as any change in these flows will not instantaneously shift the stock level; instead, the effects accumulate over time, creating the observed delay [40]. In Fig. 1, it takes time to construct, furnish, and register a new HD centre. If decisions to open new HD centres are based on information about the current gap between supply and demand, this dynamic can lead to a period of undersupply followed by oversupply.

Process to develop model structure

The preliminary model structure was based on a causal loop diagram, which had been developed iteratively in consultation with stakeholders [36]. In line with the policy goals defined by the working group, which related to financial sustainability and maintaining system capacity for PD, the boundary of the SD model was defined as factors influencing the change in number of dialysis patients and proportion of new dialysis patients selecting HD after the 2022 policy change. We therefore did not include components of the causal loop diagram related to quality assurance changes or for PD system investment prior to the 2022 policy change as modifiable factors in the model.

Incidence of chronic kidney disease in the Thai population was modelled as an exogenous variable, meaning that it was not influenced by any other variables in the model, and modelled to increase linearly over time. Patient choice between HD, PD, and CCC, timing of dialysis initiation, and death rate of dialysis patients were all influenced by feedback loops within the model related to supply constraints for HD (including vascular access services), competition between private HD centres, and availability of dialysis nurses. The rate of HD and PD patients receiving transplant or transitioning to CCC was assumed to be constant.

The preliminary model went through an iterative process of testing the boundaries, structure, and functional forms; calibration and empirical validation of model behaviour; and revision of model structure until the resulting model structure and parameter sets were both logical based on existing knowledge and coherent with renal registry data (Fig. 2). Due to challenges of reconvening large groups of stakeholders, we consulted the literature and the secretariat of the policy working group during each model iteration to ensure coherence with existing knowledge.

During this iterative process, the main changes made were related to the supply components, with three major changes implemented. First, we removed the stocks for HD centres and HD nurses after extreme values and boundary adequacy testing showed that this had negligible impact on total number of HD

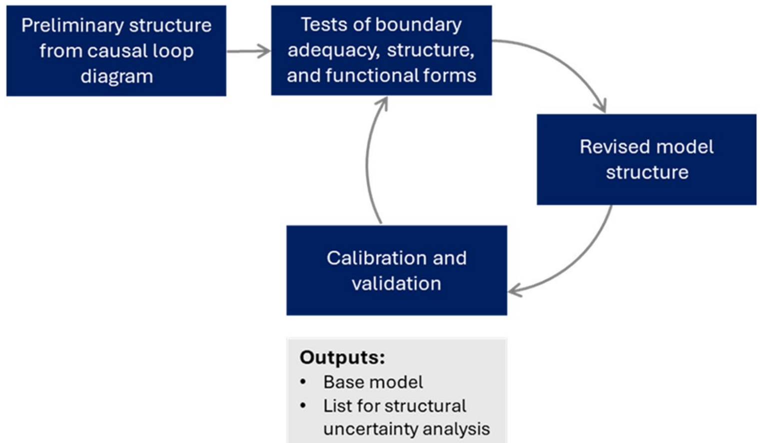

Fig. 2 Process to iteratively develop model structure

patients over a 5-year time horizon (Additional file 1: Table S1a). In the revised model, HD system stress is modelled as proportional to the rate of change in HD patients, rather than absolute capacity, reflecting the observation that system stress arises from adaptation to changes rather than static supply constraints. In the context of this model, HD system stress reflects reduced HD session length and reduced infection control measures to accommodate a higher number of patients per centre, shortages and turnover of HD nurses as HD supply increases, and burnout of HD nurses with a higher workload. Delays in HD initiation are not explicitly modelled, as financial incentives and lack of regulatory oversight meant that limited capacity triggered lower quality dialysis sessions, as opposed to delayed initiation [36].

Second, we removed the stocks for PD centres and PD nurses from the model, as this was the only structural or parameter analysis that removed model behaviour that was not consistent with pattern of the data (Additional file 1: Table S1a). The final model structure assumed that chronic underinvestment in the PD nurse workforce was reflected in the baseline PD death rate, consistent with findings from the causal loop diagram [36].

Finally, we added a separate stock for HD patients with temporary vascular access, due to the presence of a reinforcing loop and strong influence of vascular access rates on total HD patients (Additional file 1: Table S1a). A full summary of the changes made to the model structure and testing of alternative functional forms are detailed in Additional file 1: Tables S1a and S1b, respectively, with the preliminary and revised model structure in Additional file 1: Figs. S1a and S1b.

Model structure

The structure of the model is illustrated by the stock and flow diagram in Fig. 3. We modelled the key accumulations as stocks: (1) the financial incentive paid per patient per session to physicians ("doctor fee"), (2) number of HD patients, and (3) number of PD patients. To capture important clinical factors that affect outcomes, we further divided HD patients into sub-stocks based on two factors: type of vascular access (temporary or permanent) and clinical suitability for CCC (patients who would have a higher quality of life on CCC are referred to as "CCC suitable"). This structure allowed us to better model HD death rates, which depend on proportion of patients with temporary vascular access and proportion of CCC-suitable patients receiving HD. We did not explicitly model CCC-suitable patients who initiate dialysis on PD, as these patients received dialysis under the PD-first policy and were therefore reflected in the baseline PD incidence and death rates, whereas patients who would have received CCC under the PD-first policy were a source of new HD patients following the 2022 policy change.

Prior to the 2022 policy, the model includes two types of incident dialysis patients: PD-eligible and HD always. PD-eligible patients receive PD whilst patients that are not eligible for PD ("HD always") receive HD. We defined PD-eligible patients according to the guidance developed by the Nephrology Society of Thailand, which lists medical contraindications (e.g. severe abdominal adhesions) and mental or social contraindications (e.g. blind with no caregiver) that determine whether a patient is eligible for PD. There is net switch of patients from PD to HD at a fixed baseline rate, due to health reasons such as catheter failure, infection, or dialysate leakage [41].

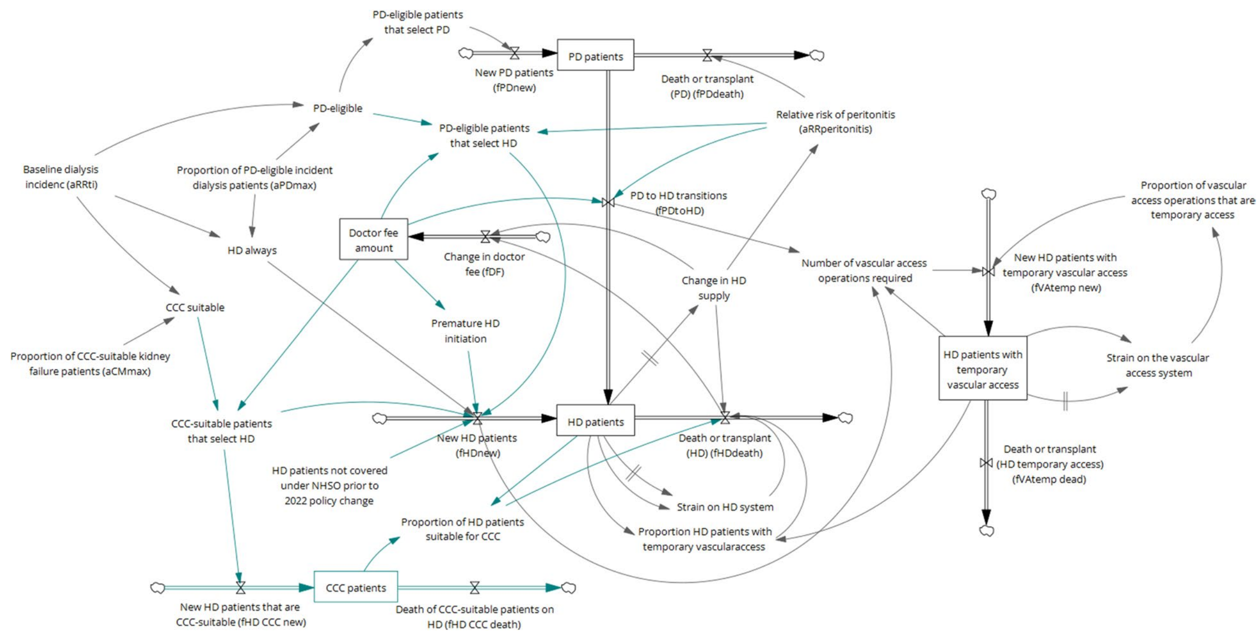

Fig. 3 Stock and flow diagram of model structure. Boxes represent stocks; double arrows represent flows; arrows in grey represent relationships that are always present; green arrows represent those that are only switched on following the 2022 policy change; and double lines || represent time delays. Additional file 1: Fig. S1b shows the model structure with feedback loops highlighted. CCC, comprehensive conservative care; HD, haemodialysis; NHSO, National Health Security Office; PD, peritoneal dialysis

A proportion of new HD patients (and PD patients switching to HD) initiate HD with temporary vascular access using a tunnelled or non-tunnelled catheter. The proportion of HD patients with temporary vascular access depends on a fixed proportion of urgent start patients and a variable proportion that depends on strain on the vascular access (VA) system, caused by a higher rate of change in patients with temporary access compared to a reference time point in the past. Patients with temporary access require another vascular access operation after a fixed length of time, whereas the model assumes that patients with permanent access (arteriovenous fistula or graft) will not need a subsequent vascular access operation. HD death rate depends on the proportion of patients with temporary vascular access as well as strain on the HD system (described previously). Both HD death rate and HD supply are modelled to change the average amount paid for the doctor fee, due to increased competition between private HD centres. Changes in HD supply affect relative risk of peritonitis and death rate of PD patients, to reflect the increased rates of PD nurse transition to HD.

Following the 2022 policy change, there are two main changes in the model related to incident dialysis patients and HD death rate. Firstly, PD-eligible patients may initiate dialysis on either HD or PD. The proportion of PD-eligible patients selecting HD in the model depends on a fixed preference for HD or PD that is not modified by other components of the model, as well as a modifiable component that depends on relative risk of peritonitis and the doctor fee. Rate of PD to HD transitions is similarly moderated by PD nurse transition to HD with increases in HD supply and the doctor fee. Secondly, there are three additional sources of new HD patients: CCC-suitable patients selecting HD, premature HD initiation patients ("HD premature"), and HD incident patients that would not have registered for dialysis under NHSO prior to the 2022 policy change ("HD other"). The proportion of CCC-suitable patients selecting HD depends on fixed patient preference for CCC or HD and a modifiable component that depends on the doctor fee. Premature HD initiation scales directly to the doctor fee, whereas HD other is a fixed percentage of baseline dialysis incidence. Proportion of HD patients that are CCC-suitable affects the HD death rate.

Functional forms

Functions in the model are detailed in Additional file 1: Table S1c. Rates of change were calculated by time delays in the model and modifiable patient choice was modelled as a sigmoidal curve, under the assumption that at very low or very high values, there is smaller impact from incremental change in a factor influencing choice (e.g. financial incentives or peritonitis rates). Equations were solved using the dede solver from the deSolve package in R, using the lsoda method [42]. Since the purpose of the model was to provide 10-year projections, in line with policy goals, the unit of time was months. Time steps of 0.25 months were used, which represents one quarter of the smallest delay in the model. Discontinuities in the model from switching on/off parts of model structure following policy change were handled using the approxfun interpolation function in R and spikes in number of new HD patients on 1st February 2024 were added as events. All code is available in the Zenodo repository: https://doi.org/10.5281/zenodo.14987793 [43].

Parameter estimation and calibration

The model was populated with data from national registries, published literature, and expert opinion (Additional file 2: Table S2a) [35, 44–48]. Published literature was identified from a search of PubMed by a single researcher, following which nephrologists on the working group or secretariat were consulted to ensure that no relevant articles or data sources had been omitted.

Since incidence of chronic kidney disease is projected to increase over time [49], we estimated baseline dialysis incidence coefficients through linear regression of renal registry data from 2016 to 2021. We defined baseline dialysis incidence as the incidence of kidney failure patients under UCS best-suited to dialysis (for which we used a proxy of the dialysis incidence under the PD-first policy). The three new sources of HD patients after the 2022 policy change (as described above) were modelled as additional dialysis incidence above baseline. Time delays for changes in HD supply were estimated by optimising the fit between number of HD patients and number of HD centres between 2018 and 2022 from a national database [28]. Methods for all parameter estimation are provided in Additional file 2: Table S2b [28, 50].

Calibration estimated factors in the model that could not be estimated from empirical data, such as factors to scale the relationship between two variables. We conducted calibration for sub-models where possible [51]. For the main calibration, parameters were calibrated to datasets related to the main policy goals, namely total dialysis patients and proportion of incident dialysis patients on PD. Factors affecting total dialysis patients were calibrated first, since factors affecting PD-eligible patient choice have minimal impact on total number of patients.

Additional file 2: Table S2c [28, 52, 53] shows the calibrated parameters and calibration datasets. Calibration was conducted using the modCost and modFit algorithms from the FME package in R [54], following the steps outlined by Duggan [55]. In all instances, model calibration was run multiple times with variations in the starting value and upper/lower bounds. If the calibrated value was not stable to the calibration starting conditions, we used grid search and conducted hand calibration to identify alternative calibration sets.

We calibrated parameters from parts of the model structure that were switched on prior to the 2022 policy change first using data from 2019 to 2021 (calibration period 1) and parameters that were only active after the policy change from March 2022 to February 2023 (calibration period 2). Vascular access data has only been reported from 2020 and is reported quarterly, so we calibrated using the full dataset up to the end of 2022.

Validation

A number of steps were taken to validate the model. Face validation of the model structure, parameters, and outputs was conducted by members of the policy working group secretariat. During model development, boundary adequacy, extreme conditions, and behaviour sensitivity tests were used to validate model structure [56, 57]. Model behaviour was validated by empirical comparison with the data from March 2023 to February 2024 (the period directly after model calibration), for pattern anticipation [56]. Model behaviour was compared with data for the two outputs of interest: total dialysis patients and proportion of incident dialysis patients on PD. Since the goal was to inform policy over the next 10 years, we did not look for the model to capture monthly oscillations but instead checked for overall direction and magnitude.

Policy projections

The model projected number of HD and PD patients over a 10-year time horizon (2025–2034) under the 2022 policy (base case) and under alternative policy scenarios. The primary metrics used to compare policies were percentage of new dialysis cases selecting PD after 3 years, total dialysis patients over 10 years, and HD death rate over 10 years. Only HD death rate was explicitly modelled as it was a major concern following the 2022 policy change [21]. We also reported profile of new HD patients (e.g. PD-eligible, premature initiation) to show the extent to which each policy improved appropriate dialysis initiation.

A set of 12 policy interventions had been proposed from research projects to inform the working group recommendations, including literature reviews [15, 58], causal loop diagram [36], and situational analysis of changes after the 2022 policy in Thailand (Phannajit J, Praditpornsilpa K, Tungsanga K: A promising start, a troubling end: the fallout of Thailand's 2022 universal renal dialysis policy, submitted). For each of the proposed policies, we modified the model diagram to show the theory of change. Since the model diagram does not show the relative magnitude or importance of loops [59], we conducted the base case analysis (i.e. continuation of the 2022 policy) to identify structures in the model that were most likely to affect achievement of the policy goal to have 50% new patients selecting PD. We then shortlisted the proposed policy interventions that targeted high-impact structures in the model.

Additional file 3: Figs. S3a to S3k show the modified model structure for each of the 12 proposed policy interventions. Given the profile of new patients selecting HD in the base case analysis, the research team shortlisted policy interventions for further analysis if they either (1) prevented premature HD initiation, or (2) reduced proportion of incident HD patients across at least three categories (e.g. PD-eligible, CCC-suitable, and HD other). According to these criteria, we selected the following five policies (Additional file 3: Table S3) [15, 21, 36, 58].

- Pre-authorisation: approval of patients by provincial committees prior to dialysis initiation.
- Doctor fee regulation: restrictions on private service provider payments to nephrologists for HD patient referral.
- Education: patient education by multi-disciplinary teams to support patients to select an appropriate treatment for kidney failure, initiated during chronic kidney disease stage 4.
- Quality-based HD payment: change from fee-for-service, in which service providers are reimbursed per HD session, to quality-based payments per HD patient.
- Global budget: total budget for dialysis provider payment is capped per year, so that fee per patient decreases as total dialysis patients increases.

Policy implementation was modelled as immediately effective. This was because the policy working group had estimated that all of the proposed policies could be fully implemented within 3 months, which is a relatively short period of time in relation to the 10-year projections.

Uncertainty analysis

We conducted several types of analyses to assess the robustness of model results. For the base case, we conducted deterministic sensitivity analysis of parameter uncertainty using confidence intervals from the literature or plausible ranges from expert opinion (Additional file 2: Table S2a) [44]. Since we had insufficient data to estimate priors for all model inputs, we conducted global sensitivity analysis using Latin hypercube sampling as an efficient method by which to consider total parameter uncertainty [60]. We conducted structural uncertainty analysis related to the influence of the doctor fee and peritonitis rates on patient choice, as these functions were identified as having a potentially important impact during model development (Additional file 1: Table S1b). For each structural change, we re-calibrated the model (Additional file 2: Table S2d).

For each of the policy interventions modelled, we assessed uncertainty through three complementary approaches. Firstly, we compared policies under the alternative base model structures described above, to see whether model structure could affect the best performing policy option. Secondly, we conducted one-way deterministic sensitivity analysis to identify which parameter uncertainty could influence whether or not the policy targets were met. Thirdly, we conducted scenario analysis to model different implementation of each policy option (including partial compliance and potential unintended consequences from different stakeholder responses to policy change). Scenarios were informed by a scenario thinking study (Botwright S, Yongphiphatwong N, Teerawattananon Y, et al: Accounting, submitted) and literature relevant to the policy proposal in question.

Results

Base case (2022 policy)

The base case projection estimated approximately 117,000 dialysis patients by the end of 2029 under the 2022 policy (Additional file 4: Fig. S4a). Between 2025 and 2029, an average of 12% of patients were projected to select PD at the time of dialysis initiation, 32% of new dialysis patients were estimated to initiate HD prematurely, and 6% of patients were projected to have a higher quality of life on CCC (Additional file 4: Fig. S4b). Similar to the structural analysis (Additional file 1: Tables S1a and S1b), uncertainty in parameters affecting the doctor fee, temporary vascular access rates, and PD-eligible patient choice were most influential on model outcomes (Additional file 4: Figs. S4c and S4d). Results from the Latin hypercube sampling are shown in Additional file 4: Figs. S4e and S4f, showing a high level of variability that tends towards a lower projection of total dialysis cases and a steeper decline in proportion of new dialysis patients selecting PD over time.

Comparison of policy interventions

Proportion of new dialysis patients selecting PD

None of the five proposed policy interventions reached the target of 50% incident dialysis patients on PD by the end of 2027 (Fig. 4 and Additional file 5: Table S5a). The best performing policy option was restricting payment of the doctor fee, which was projected to result in 26% of incident patients selecting PD, followed by global budget and pre-authorisation (23% each). Restricting the doctor fee was the best performing option across all structural analyses, though none of the policies achieved proportion of PD incidence above 30% (Additional file 5: Table S5b),

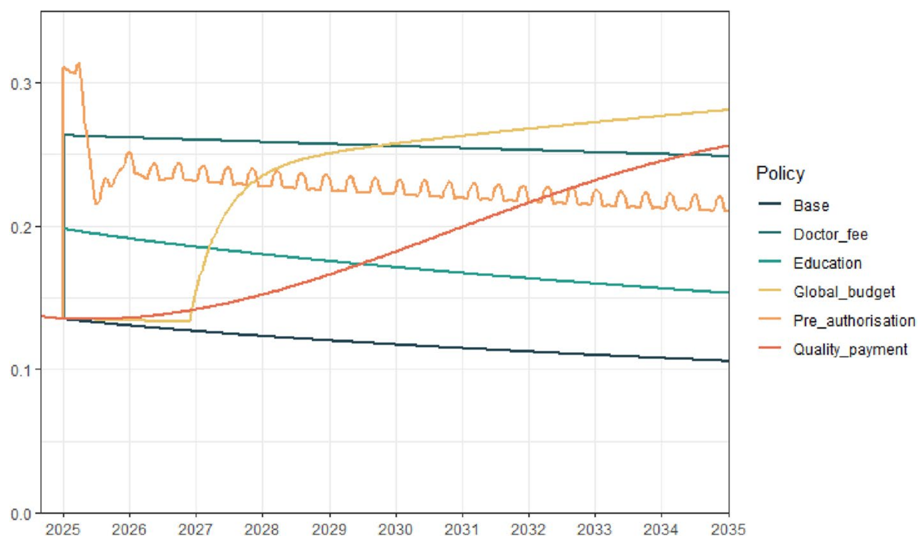

Fig. 4 Projected proportion of new dialysis patients selecting peritoneal dialysis (PD) between 2025 and 2034, under alternative policy interventions. Base, base case analysis; Doctor_fee, doctor fee regulation; Education, patient education by multi-disciplinary team; Global_budget, global dialysis budget; Pre_authorisation, patient approval of provincial committee prior to dialysis initiation; Quality_payment, quality-based service provider payments per HD patient

increasing confidence in model findings that no single intervention can achieve the policy target but restricting the doctor fee is likely most effective [37]. In the one-way sensitivity analysis, only two parameters increased proportion of incident dialysis patients on PD to above 30%: inherent preference for HD among PD-eligible patients that is not modified by peritonitis risks or the doctor fee (for pre-authorisation and doctor fee regulation) and the starting value of the doctor fee in the model (for the education policy) (Additional file 5: Table S5c).

Although the doctor fee showed the strongest immediate impact, our temporal analysis revealed important differences in how policy effectiveness evolved over time (Fig. 4). Global budget and quality-based payments were the only policies projected to show an increase in proportion of new dialysis patients selecting PD over time, with both projected to outperform doctor fee regulation over a 10-year period. The scenario analysis suggested that performance of all policies would decrease over time unless the policy either prevented increases in financial incentives to doctors and healthcare workers, through strict regulation of financial incentives or successfully limiting available funds to pay the doctor fee, or inadvertently restricted access to HD (global budget) (Additional file 6: Figs. S6a–S6e) [7, 9–11, 61, 62]. To illustrate, a highly effective abolition of financial incentives was modelled to improve doctor fee regulation performance over time, approaching 30% within 10 years, whereas quality-based payments that led to private providers selecting healthier patients as opposed to changing spending patterns could lead to fewer dialysis patients selecting PD over time, approaching 10% over 10 years.

Total dialysis patients and HD death rates

Projected total dialysis patients and death rates over 10 years are shown in Figs. 5 and 6, respectively. Pre-authorisation is modelled to bring the greatest reduction in total dialysis patients across all time periods modelled, as it is the only policy to prevent inappropriate HD initiation (Additional file 5: Figs. S5a and S5b). Over a 10-year period, a pre-authorisation system is also modelled to have the lowest HD death rates, as it is the only policy to prevent CCC-suitable patients from initiating HD and it has low strain on the HD and vascular access systems due to a slow rate of increase in total HD patients.

The next greatest reductions in total dialysis patients are observed with doctor fee regulation and global budget policies. For doctor fee regulation, the reduction predominantly comes from a marked reduction in premature initiation of HD. HD death rates show an initial drop but are very slightly higher than the base case after 10 years due to a higher percentage of CCC-suitable patients (Additional file 5: Figs. S5a and S5b). For global budget, once HD demand exceeds available supply, the model projects a high increase in HD death rates, from strain on the system, alongside reduced access to dialysis services, making it the only policy to decrease proportion of HD always patients (Additional file 5: Fig. S5b).

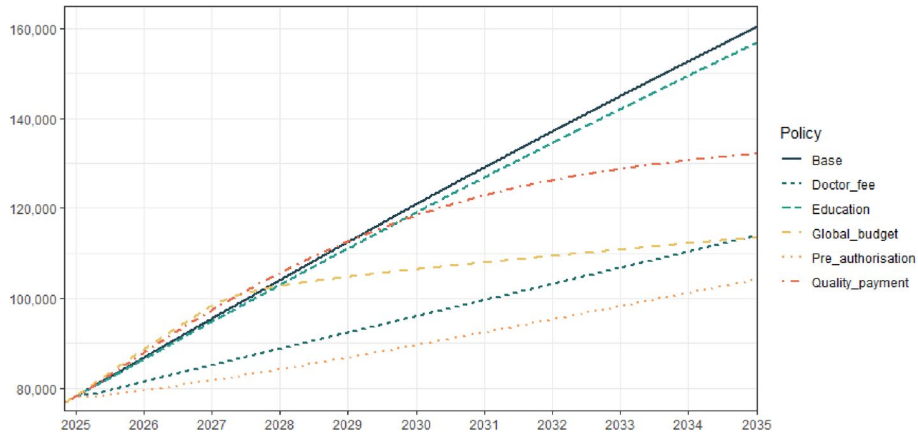

Fig. 5 Projected total dialysis patients between 2025 and 2034, under alternative policy interventions. Base, base case analysis; Doctor_fee, doctor fee regulation; Education, patient education by multi-disciplinary team; Global_budget, global dialysis budget; Pre_authorisation, patient approval of provincial committee prior to dialysis initiation; Quality_payment, quality-based service provider payments per HD patient

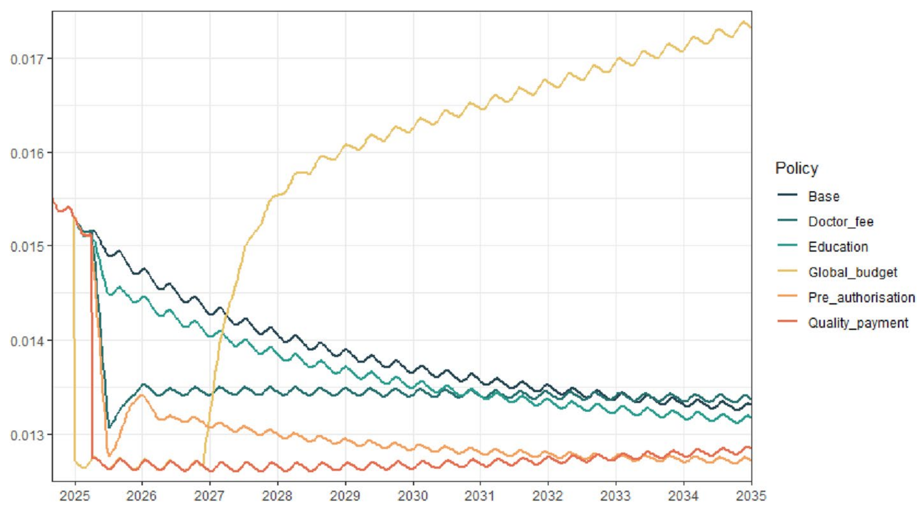

Fig. 6 Projected death rate (% per month) of haemodialysis (HD) patients between 2025 and 2034, under alternative policy interventions. Base, base case analysis; Doctor_fee, doctor fee regulation; Education, patient education by multi-disciplinary team; Global_budget, global dialysis budget; Pre_authorisation, patient approval of provincial committee prior to dialysis initiation; Quality_payment, quality-based service provider payments per HD patient

Of note, unless private centres stop paying a doctor fee, global budget is still modelled to have a high level of inappropriate dialysis initiation (Additional file 5: Figs. S5a and S5b).

Although quality-based payments may slightly increase total dialysis patients in the short term, due to lower death rates from higher quality standards, reduction in the doctor fee to maintain quality standards whenever death rates increase under this policy is modelled to have a more pronounced effect over 10 years, reducing total dialysis patients by around 30,000 whilst also maintaining low HD death rates. By contrast, education shows minimal impact on total patients or death rates, although the scenario analysis suggested that this reduction could be greater if there is some level of reduction in financial incentives for healthcare professionals.

Combinations of policy interventions

Combining multiple policy options improved outcomes but still fell short of the 50% policy target (Additional file 5: Table S5a). The most effective policy combination was joint implementation of pre-authorisation, doctor fee regulation, education, and quality-based payment, which resulted in 45% incident patients on PD by the end of 2027, a total of 102,000 dialysis patients by the end of 2029, and an average HD death rate of 0.012% per month (which was the lowest death rate of any policy combination). Over time, proportion of new dialysis cases selecting PD increased whilst death rate of HD patients decreased. Under all structural and parameter sensitivity analyses, proportion of new patients selecting HD within 3 years was between 40 and 50%, with the exception of HD preference among PD-eligible patients, which varied between 34 and 61% at extreme parameter values, dependent on model structure (Additional file 5: Table S5e).

Model validation

The results from model calibration and validation are presented in Additional file 7: Figs. S7a and S7b. Overall, the model effectively captured the long-term dynamic behaviour trends. The main variations from renal registry data occurred during the calibration periods. During calibration period 1 (prior to the 2022 policy change), the model did not pick up fluctuations in baseline dialysis incidence in 2021 (as it is treated as exogenous to the model) or a decrease in proportion of incident patients selecting PD prior to the 2022 policy change. During calibration period 2, the model did not show a stagnation in total dialysis patients around 2 months after the 2022 policy change, which is likely due to a peak in deaths in April 2022, corresponding to a peak in excess COVID-19 mortality in Thailand at the same time [63]. Since number of new dialysis cases from the model is in line with renal registry data, this suggests that the model may poorly represent short-term changes in death rates after shocks to the system but effectively generates long-term behaviour.

Discussion

In this study, we developed a SD model to evaluate which policy interventions could achieve a set of targets to balance dialysis supply and demand in Thailand. Our results suggest that co-implementation of pre-authorisation, doctor fee regulation, education, and quality-based payment policies could increase the proportion of new dialysis patients selecting PD to over 45% within the next 3 years and decrease total dialysis patients by 60,000 within the next 10 years whilst decreasing HD death rates. Comparing individual policies, restricting payments of the doctor fee would have greatest impact in increasing the proportion of dialysis patients selecting PD over the next 3 years, and this finding was consistent when testing different model structures. The most important source of uncertainty in our analysis was the factors affecting payment of the doctor fee and factors driving PD-eligible patient choice. Coupling education interventions with the doctor fee regulation is projected to address this uncertainty, as factors decreasing the effectiveness of doctor fee regulation are countered by improvements in the effectiveness of education and vice versa (see Table S5c).

Our findings are not aligned with a review of policies to increase uptake of PD, which did not identify moderation of financial incentives to individual doctors or pre-authorisation mechanisms as effective policy levers [15]. This is likely because the review mainly included studies from tax-funded public health systems with minimal private service provision and the majority of studies were from high-income countries that likely have stricter regulation of informal payments. We are not aware of any other LMIC that has successfully managed provision of dialysis services according to patient choice: other LMICs manage access to dialysis within resource constraints through a number of policy levers, including a PD-first policy, restricting the number of HD sessions per patient per year, prioritising patients for reimbursement of dialysis services, or implicitly through imperfect access or low-quality service provision [3, 64–66].

From a theoretical perspective, our findings are consistent with the framework for variations in healthcare put forward by Wennberg [5], as the proposed bundle of policies addresses effective care, by preventing dialysis initiation in unsuitable patients (pre-authorisation) and preference-suitable care, by moderating financial incentives for doctors (doctor fee regulation) and addressing information asymmetry between patients and providers in private healthcare systems (education). Our findings are also consistent with studies from the US linking physician behaviour with financial incentives provided by private companies [61, 67, 68]. This suggests that context-specific factors influencing patient and provider behaviour should be considered alongside literature review when identifying potential policies to address health system problems.

One of the strengths of the study is that our projections of policy performance were coupled with a scenario thinking analysis to broaden our view of potential stakeholder actions (Botwright S, Yongphiphatwong N, Teerawattananon Y, et al: Accounting, submitted), and revisions to model structure to reflect impact of policies in the Thai context (which may have different mechanisms of action to those described in the literature). The model results initially presented to the working group, based on secretariat hypotheses about how the policy may work, were more optimistic in terms of policy performance than the results presented in this paper [21]. Our revised approach provides greater information on implementation uncertainty and risk to policymakers, allowing for better policy decisions.

Another strength is that we used a variety of approaches to identify potential policy interventions, comprising literature reviews, situational analysis, and causal loop diagram (CLD) archetype solutions (a tool from systems thinking). Our results suggest that the combination of literature review and situational analysis identified the highest impact combination of policies. Although the solutions identified from CLD archetypes were generally less relevant, there are a number of reasons as to why this may be. Firstly, solutions to the CLD archetypes had been identified to address unintended consequences of policy changes in the dialysis system and was not targeted to proportion of PD patients, unlike the literature review. Secondly, during model development, populating the model with data challenged some of the assumptions in the CLD and exploratory modelling highlighted loops that were more influential on model results than others. Even in settings with limited time and capacity for SD simulation, our findings suggest that it may be beneficial to conduct exploratory modelling of the CLD in freely available software to iteratively improve model structure before conducting an analysis to identify archetype solutions.

Our study has a number of limitations, many of which are inherent to the purpose of system dynamics. Firstly, we made changes to model structure so that supply was not modelled in terms of absolute number of centres and nurses. Although this showed a better fit to the data at the national level, it is known that there is substantial heterogeneity in availability of dialysis centres and nurses between provinces [28], which could be affected unequally by different policies. A second limitation is that model calibration suggested our model may be poorly able to account for short-term increases in death rates following shocks to the system. This is most relevant for global budget, which may have higher death rates in the first few years of implementation than we have modelled. Another limitation related to calibration is that we did not account for excess COVID-19 mortality, as the calibration process aimed to pattern match for long-term model behaviour. Since short-term mismatches between our model's projections and total dialysis cases from the renal registry data correspond to the peaks in excess COVID-19 mortality in Thailand [63] and the model was able to project behaviour during the validation period with reasonable accuracy, we believe this limitation did not have a major effect on results. Thirdly, in determining model structure, we emphasised factors that would change the relative performance of policy options over accurate estimation of number of cases. We therefore did not explore changes in CKD prevalence in our modelling, and due to the very low rates of transplantation in Thailand, we did not separate transplantation from death rates in the model structure. Finally, the main source of uncertainty in the model was patient choice among PD-eligible patients, which may be better modelled through agent-based, bottom-up models than system dynamics [69], especially to capture heterogeneity in decision-making between different patient groups and to capture the complexity of patient decision-making.

Despite these limitations, our analysis suggested high confidence in our finding that combining policies to regulate doctor fee payments, approve dialysis initiation (pre-authorisation), patient education, and quality-based payments would have the greatest impact. In the model, strict regulation of the doctor fee was the only way to prevent proportion of PD patients from progressively decreasing over time. It has been found that speaker and consulting fees for specialists can have a similar (albeit reduced) effect to direct financial payments to physicians [61]. We therefore recommend a holistic approach to abolishing unregulated payments within the system, similar to the principles to manage conflicts of interest within policy processes [70–72], to encourage culture change over time.

Another recommendation from our research regards the policy goals. We showed that performance of policy options may substantially improve or worsen over time, suggesting that policy goals should monitor targets on an annual basis as opposed to setting a one-off target, with governance mechanisms in place to adapt the policy over time as new knowledge is gathered. Furthermore, the current policy goals aim to reduce total number of dialysis patients without compromising on patient quality of care and have therefore been framed around total incident patients and total budget [21]. However, our analysis showed that the current targets could lead to prioritisation of policies such as global budget, which could worsen patient outcomes. Including a specific target around quality of care or death rates could better align the stated targets with actual policy goals.

Our finding that none of the policy combinations would achieve the 50% PD utilisation target presents policymakers with a fundamental dilemma: pursue imperfect improvements within the current patient choice framework or return to the original PD-first policy, despite its restrictions on patient choice. This decision involves weighing competing values of patient autonomy, system efficiency, and equitable resource allocation, as the policy interventions in our analysis allowing greatest patient choice would require resources to be diverted away from other health programmes to cover the much higher budget and trained healthcare personnel requirements for HD compared to PD or CCC.

The data provides some justification for reconsidering a PD-first approach. A study in Thailand estimated that there is 10% leakage within UCS, meaning that UCS beneficiaries receive 10% of their healthcare services outside of UCS (most often through out-of-pocket spending) [22]. Data from patients switching to NHSO following the 2022 policy change suggests that under the PD-first policy, there was less than 10% leakage for dialysis, and most likely less than 5% [50]. From this perspective, the 2008 policy was aligned with service provision among other disease areas of UCS and it may therefore be justified to return to the PD-first policy for equitable allocation of resources between the KRT programme and other disease areas [66].

It is worth noting, however, that the 50% PD target was estimated based on budget impact projections that did not account for changes in total number of dialysis patients (Teerawattananon Y, Chavarina KK, Phannajit J, et al: Nature medicine commission on dialysis policy in low- and middle income countries: from policy to pivotal impact: Thailand's dialysis reform journey and its unexpected consequences, submitted). Since our model estimates that total dialysis patients would reduce by 60,000 (around 1/3) with the proposed package of policy interventions (due to improved appropriate care), it is highly likely that overall budget impact targets would be met even without meeting the 50% PD target. Following a policy decision, we recommend ongoing monitoring to validate projections of the model, with periodic policy review to continuously improve the balance between equitable allocation of resources and patient choice in Thailand.

Conclusions

The most effective policies in this analysis had been identified from situational analysis of the Thai context, highlighting the limitations of relying on experience of health system policies from other jurisdictions, particularly in settings with unregulated financial incentives and practices. We showed that coupling policies with complementary mechanisms of action could both increase policy impact and effectively address the key sources of uncertainty in our analysis. Our study also highlighted that different policies show different trends in performance over time, suggesting that policy goals and targets should not be set for single time points. Our findings demonstrate the value of systems thinking for health policy design, offering policymakers an approach to navigate the complex interplay between financial incentives, provider behaviour, and patient choice that shapes healthcare outcomes beyond what conventional policy analysis can achieve.

Abbreviations

CCC	Comprehensive conservative care
HD	Haemodialysis
KRT	Kidney replacement therapy
LMIC	Low-income and middle-income countries
NHSO	National Health Security Office
PD	Peritoneal dialysis
SD	System dynamics
UCS	Universal Coverage Scheme (the biggest public health insurance scheme in Thailand)
UHC	Universal Health Coverage

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12916-025-04522-z.

Additional file 1. Tables S1a–S1c and Figures S1a–S1b. Table S1a—modifications to model structure. Table S1b—structural analysis of functional forms. Table S1c—functions in the base model. Figure S1a—preliminary model structure. Figure S1b—revised model structure.

Additional file 2. Tables S2a–S2d. Table S2a—data sources for model parameters. Table S2b—parameter estimation. Table S2c—calibrated parameters. Table S2d—alternative calibration sets for structural analysis.

Additional file 3. Table S3 and Figures S3a–S3k. Table S3—shortlisting of proposed policy options to model. Figures S3—model diagram for: preauthorisation policy (a), key performance indicator of quality assurance capacity, (b), quality-based fee-per-patient for providers (c), regulations for dialysis nurse hours (d), demand forecasting for capacity investments (e), restricting doctor fee payment (f), patient education by a multi-disciplinary team (g), comprehensive conservative care protocols (h), continuous quality improvement scheme (i), global budget (j), and bundle payments (k).

Additional file 4. Figures S4a–S4f. Figure S4a—base case projection of number of dialysis patients. Figure S4b—profile of new patients under the base case scenario. Figure S4c—deterministic sensitivity analysis of base case model (total dialysis patients). Figure S4d—deterministic sensitivity analysis of base case model (proportion of new patients selecting peritoneal dialysis). Figure S4e—Latin hypercube sampling (total dialysis patients). Figure S4f—Latin hypercube sampling (proportion of new patients selecting peritoneal dialysis).

Additional file 5. Figures S5a–S5b and Tables S5a–S5e. Figure S5a—projected profile of new dialysis patients under each policy (2027). Figure S5b—projected profile of new dialysis patients under each policy (2034). Table S5a—projected outcomes under each policy. Table S5b—structural uncertainty analysis. Table S5c—deterministic sensitivity analysis. Table S5d—outcomes over time for combination of policy options. Table S5e—uncertainty analysis for combination of policy options.

Additional file 6. Figures S6a–S6e. Figure S6a—scenario analysis for the pre-authorisation policy. Figure S6b—scenario analysis for the doctor fee policy. Figure S6c—scenario analysis for the education policy. Figure S6d—scenario analysis for the quality-based payment policy. Figure S6e—scenario analysis for the global budget policy.

Additional file 7. Figures S7a–S7h. Figure S7a—validation of model behaviour (total dialysis patients). Figure S7b—validation of model behaviour (proportion of new dialysis patients selecting peritoneal dialysis). Figure S7c—calibration of parameters associated with peritoneal dialysis death (prior to 2022). Figure S7d—calibration of parameters associated with haemodialysis death (prior to 2022). Figure S7e—calibration of parameters associated with new haemodialysis cases (1-year after 2022 policy change). Figure S7f—calibration of parameters associated with proportion of patients selecting peritoneal dialysis (1-year after 2022 policy change). Figure S7g—calibration of parameters associated with switch from peritoneal dialysis to haemodialysis (1-year after 2022 policy change). Figure S7h—calibration.

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Authors' contributions
Conceptualisation and methodology: SB, JQ, IM, LKNN; data curation: YT, JP, JS, NY, KKC; formal analysis: SB; validation: YT, JP, JS, NY, LKNN; visualisation: SB; writing – original draft: SB; writing – reviewing and editing: YT, JQ, IM, LKNN; supervision: YT, JQ, IM, LKNN; project administration: JS, KKC; funding acquisition: YT, JS, KKC. All authors read and approved the final manuscript.

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Data availability
The data and model code for the current study are available in the Zenodo repository: [https://doi.org/https://doi.org/10.5281/zenodo.14987793].

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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