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ORIGINAL ARTICLE

The Payer License Agreement, or "Netflix model," for hepatitis C virus therapies enables universal treatment access, lowers costs and incentivizes innovation and competition

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Abstract

Background and Aims: High unit prices of treatments limit access. For epidemics like that of hepatitis C virus (HCV), reduced treatment access increases prevalence and incidence, making the infectious disease increasingly difficult to manage. The objective of the current study was to construct and test an alternative pricing model, the Payer License Agreement (PLA), and determine whether it could improve outcomes, cut costs and incentivize innovation versus the current unit-based pricing model.

Methods: We built and used computational models of hepatitis C disease progression, treatment, and pricing in historical and future scenarios and quantitatively analyzed their economic and epidemiological impact in three high-income countries.

Results: This study had three key results regarding HCV treatment. First, if the PLA model had been implemented when interferon-free direct-acting antiviral (DAA) combinations launched, the number of patients treated and cured would have more than doubled in the first three years, while the liver-related deaths (LRDs) would have decreased by around 40%. Second, if the PLA model had been implemented beginning in 2018, the year that several Netflix-like payment models were under implementation, the number of treated and cured patients would nearly double, and the LRDs would decline by more than 55%. Third, implementing the PLA model would result in a decline in total payer costs of more than 25%, with an increase to pharmaceutical manufacturer revenues of 10%. These results were true across the three healthcare landscapes studied, the USA, the UK and Italy, and were robust against variations to critical model parameters through sensitivity analysis.

Conclusions and Relevance: These results suggest that implementation of the PLA model in high-income countries across a variety of health system contexts would improve patient outcomes at lower payer cost with more stable revenue for pharmaceutical manufacturers. Health policy-makers in high-income countries should consider the PLA model for application to more cost-effective management of HCV,

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and explore its application for other infectious diseases with curative therapies available now or soon.

KEYWORDS
cost-effectiveness analysis, epidemic, hepatitis C virus, innovative pricing, Payer License Agreement, value-based healthcare, value-based pricing and reimbursement

1 | INTRODUCTION

Pricing model evolution has impacted many industries, enabling closer linkage of price demanded by the producer and value delivered to the consumer. The shift from unit-based to volume-based pricing models typically share three critical properties: (1) initial misalignment of the time of payment to the producer and the time over which value is delivered to or consumed by the customer; (2) value delivered that varies widely depending on the customer served; and (3) zero or relatively low incremental cost of goods sold (COGS). In pharmaceuticals, the pricing of treatments in many therapeutic areas satisfy these three properties. First, the pharmaceutical company (producer) is paid upfront, though the beneficiaries—the patient, the payer, the government—accumulate value over time in outcomes improvement and/or cost avoidance. Second, the variance in value delivered can be large: the same treatment that prevents one patient's mild discomfort may prevent the next patient's death. Finally, COGS for many branded pharmaceuticals are very low relative to price after the high costs of research and development.

We first suggested the "Netflix model" for pricing curative treatments of an example disease, hepatitis C virus (HCV), after reflecting on the properties of pricing model evolution and the limited set of current solutions in healthcare.[1] This model, also called a Payer License Agreement (PLA), is based on three structural changes to traditional pharmaceutical economics: (1) the pricing basis, that is, the indivisible product or service that is sold, is the full population served by the payer, as opposed to the individual patient or treatment; (2) the value of the drug, and thus the price, is linked directly to the incremental cost avoidance; and (3) the payment is annuitized and contracted as a subscription over a period of 5 or more years. Conceptually, this is analogous to Netflix's model, where Netflix pays content providers a fee negotiated for unlimited access over a specified time while Netflix's customers capture that value differentially based on how much content they consume.

In charging upfront for value delivered variably over time, pharmaceutical companies face payer budget constraints and downward price pressure that have caused them to pursue alternative models. Differential pricing—including indication-dependent, combination therapy-based and geography-specific pricing—addresses differences in value delivered among patient segments.[2] Outcomes-based pricing, a collection of models in which the manufacturer is compensated depending on the success of the therapy for each patient using agreed-to outcomes metrics and rebate mechanisms,[3] and academic proposals using third-party financing to spread costs,[4] addresses the temporal accrual of value. Capitated pricing, where a payer determines the maximum reimbursement for the complete management of a particular disease, formalizes the definition of therapy value in relation to other sources of cost such as hospital procedures.[5] While each of these pricing models can better align value and price, none of them simultaneously addresses the crucial value differential both between patients and in time.

We are pleased that the PLA model has begun to get traction in the United States (USA) and Australia,[6–8] but believe the model would benefit from a more complete theoretical treatment. Here, we clarify the conceptual foundations for the PLA model, then quantify its potential epidemiological and economic impact. We model three different health landscapes, the USA, Italy and the United Kingdom (UK), selected for their diversity in payer structure, HCV prevalence rates, per capita healthcare budgets, overall population size and approaches to reimbursement decisions. The USA is a multi-payer, while the UK is a single payer, and Italy has a large out-of-pocket treatment cost; Italy has among the highest prevalence rates in Europe, while the USA and the UK are lower (1.2%, 0.76% and ~0.24%, respectively, in 2017[9]); annual pharmaceutical spend in the USA is $1170 per capita, the UK is $480 and Italy is $630[10]; and UK treatment decision-making is tightly linked to incremental cost-effectiveness on a QALY basis, while US private payers typically have shorter time horizons for integrating costs to make reimbursement decisions. We optimize for the interests and incentives of three key stakeholders by (1) providing universal patient access to necessary treatment; (2) reducing health system cost from

Lay summary

Pharmaceutical drugs are typically priced per pill, which often limits the number of patients who can access drugs' benefits. Because access limitations negatively impact the fight against hepatitis C, we built a subscription-based pricing model and analysed its effect on patient outcomes, payers' costs and pharmaceutical revenues. The model achieves a "win-win-win" solution to faster hepatitis C elimination with fewer deaths, lower total costs and reliable therapy revenues.

its current state; and (3) growing the incentive for pharmaceutical companies to innovate and to compete.

We chose HCV direct-acting antiviral (DAA) therapies as an example case owing to the urgency of the need and the impact of the therapy. Globally, more than 71 M people are infected with chronic HCV, with 1.8 M new cases and 400 000 deaths in 2015.[11,12] In the USA prior to COVID-19, death caused by HCV was more common than death caused by the next 60 most deadly infectious diseases combined.[13] Since 2011, DAAs have been approved for use in the USA,[14,15] in Europe and much of the rest of the world, and as of 2014, non-interferon DAA combinations achieve virological cure, or sustained viraemic response (SVR), in >95% of patients. Despite this scientific innovation, price has remained a barrier to widespread treatment access. Treating the full chronic HCV population is prohibitively expensive, costing up to 190% of total annual pharmaceutical budget at current prices on a purchasing power parity-adjusted basis, and up to 5.3 years worth of average annual individual income.[16] As a result, many health systems have restricted patient reimbursement based on liver fibrosis severity, coinfection of HIV, drug and alcohol use and prescriber type. For example, Medicaid reimbursement in 2014 for most US states (74%) required at least fibrotic stage 3 for treatment access[17] and remained at 44% of states by 2016.[18] In Europe, 46% of countries and jurisdictions required patients to have fibrotic stage 2 or higher as of 2017.[19] Critically, the cost-efficiency of treating HCV varies by disease stage and becomes less attractive at early stages.[20–22] Taken together, reimbursement criteria are inconsistent with the clinical recommendation of treatment consideration for all patients who desire HCV treatment and have no contraindications, and price is a factor in determining these criteria. That is, treatment behaviour is consistent with the logic of providing access where the value accrued, or cost avoided, is high versus the price of therapy and limiting access where the value is low versus the price of therapy.

WHO identifies HCV as an epidemic, and has put in place ambitious targets to reduce incidence by 80%, achieve 90% diagnosis rate, treat 80% of eligible HCV patients and reduce HCV-related mortality by 65% by 2030.[23] However, to achieve these targets requires substantial improvement in treatment efforts and reduction in current restrictions for DAA reimbursement,[11] and only 12 countries globally are on track to achieve these targets.[9] In this paper, we demonstrate that implementing the PLA model will achieve the WHO targets faster than with traditional industry economics while reducing payer's overall costs and compensating the pharmaceutical manufacturers with greater and more stable revenues. We first show that HCV disease progression results in significantly higher expected costs in later patient cohorts, motivating early-stage intervention as cost-saving. We then model the epidemiological impact if PLAs had been employed at the launch of DAAs in 2014. We finally analyse the epidemiological and economic impact of shifting to a PLA model in 2018–2030, and determine the cost-effectiveness versus the current commercial model.

2 | METHODS

2.1 | Disease Burden Model

Our analysis included three countries, the USA, Italy and the UK. The cost input data for each country along with their source is shown in eTable 1B. We analysed both direct costs for economic analyses and, for QALY analyses only, costs associated with the burden of disease and their impact to society. Direct costs are in 2017 prices and, where relevant, converted to US dollars using the exchange rate on December 31, 2017.[24] Future direct and disease burden costs were discounted at a 3% rate. For each country, we modelled several scenarios and time periods (see Appendix S1). A previously described, Markov model was used to forecast viraemic HCV prevalence over time.[25–27] The model was modified to follow individual 5-year age segments as they evolve over time.

2.2 | Economic analysis

To calculate both direct and disease burden costs associated with each scenario, an economic impact module (EIM) was added to the disease burden model. In this analysis, we calculated direct costs as both screening and healthcare, including inpatient, outpatient and medication excluding anti-viral treatment. Annual total screening costs were calculated by first determining the number of people needed to screen in order to find one undiagnosed anti-HCV positive case (Equation 1). The total number of annual anti-HCV positive screens was found by first multiplying the number needed to screen by the number of newly diagnosed asymptomatic and RNA- cases, and then adding the number of newly diagnosed symptomatic cases (Equation 2). The annual number of RNA screens was found by adding together the percent of newly diagnosed that were RNA+ and RNA- (Equation 3).

Equation 1. Number of people needed to screen to find one new case of viraemic HCV

$$\text{Number needed to screen to find one new case}_t\ (\text{NNS}) = \frac{1}{\text{Prevalence of undiagnosed anti}-\text{HCV}^+\ \text{cases}_t}$$

Equation 2. Annual screens for anti-HCV+ in year t

$$\text{Annual screened for anti}-\text{HCV}_t^+ = \text{Newly Dx, Symptomatic\&linked to care}_t + (\text{Newly Dx, Asymptomatic or not linked to care}_t + \text{Newly Dx, Anti}-\text{HCV}^+, \text{RNA}_t^-) \times \text{NNS}$$

Equation 3. Annual screens for HCV RNA+ in year t

$$\text{Annual screened for HCV RNA}_t^+ = \text{Newly Dx, HCVRNA}_t^+ + \text{Newly Dx, Anti}-\text{HCV}^+, \text{RNA}_t^-$$

In the screening calculations, we assume that with an efficient database, individuals will be screened no more than an average of 1.5 times. We assumed that initial screening efforts will target higher risk populations where the prevalence is five times that of the general population, decreasing linearly to match that of the general population by 2060.

Unit prices of treatments was based on multiple, country-specific industry forecasts,[28,29] with 3% annual discounting. Screening was assumed to be $20 for both antibody and RNA diagnostics, with 3% discounting after 2018.

The measure of the burden of disease was assessed in terms of quality-adjusted life years (QALYs), which were based on time spent in each of the various disease stages. Different QALY utility weights were applied to each stage of the disease.[20] Differences in QALYs over time were used to compute incremental cost-effectiveness ratios (ICERs) for comparisons among pricing model scenarios.

2.3 | Sensitivity analysis

Our study included sensitivity analyses with Monte Carlo simulations, which were performed using Crystal Ball, an Excel add-in by Oracle. We modelled uncertainty for all epidemiology inputs and healthcare costs (eTables 1 and 2) using a Beta-PERT distribution.

3 | RESULTS

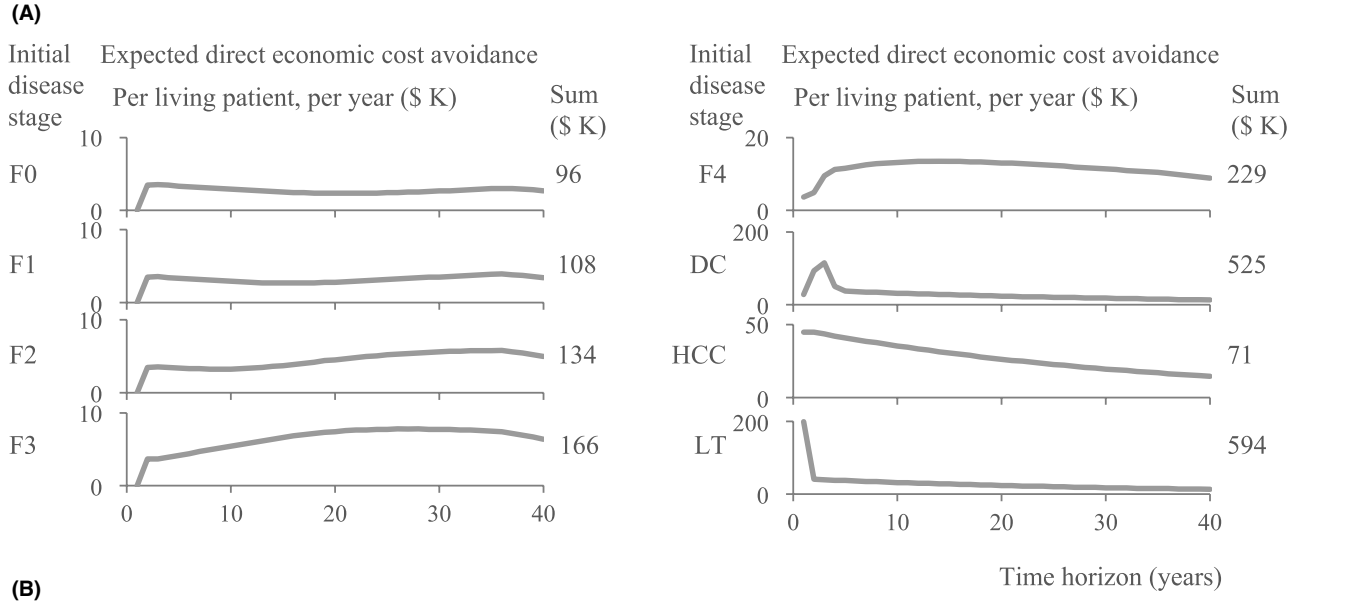
3.1 | Value and timing of non-treatment cost avoidance

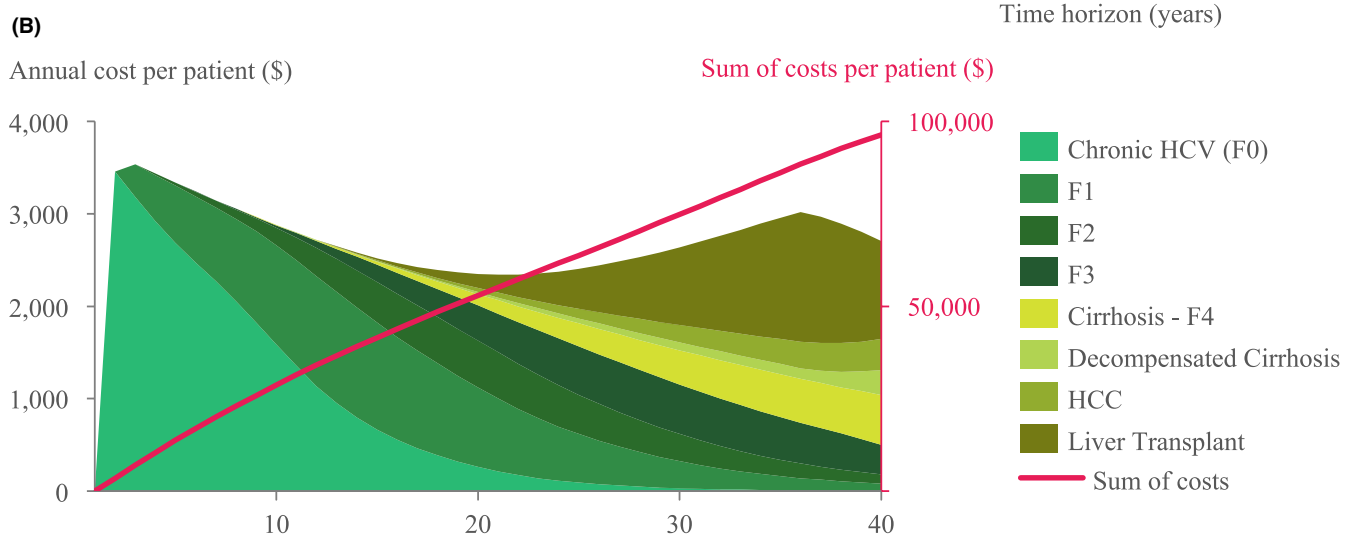
We developed a dynamical systems-based Markov model tuned using historical epidemiological data to forecast disease progression and associated health system costs for hepatitis C patients in three health landscapes, the USA, Italy and the UK.

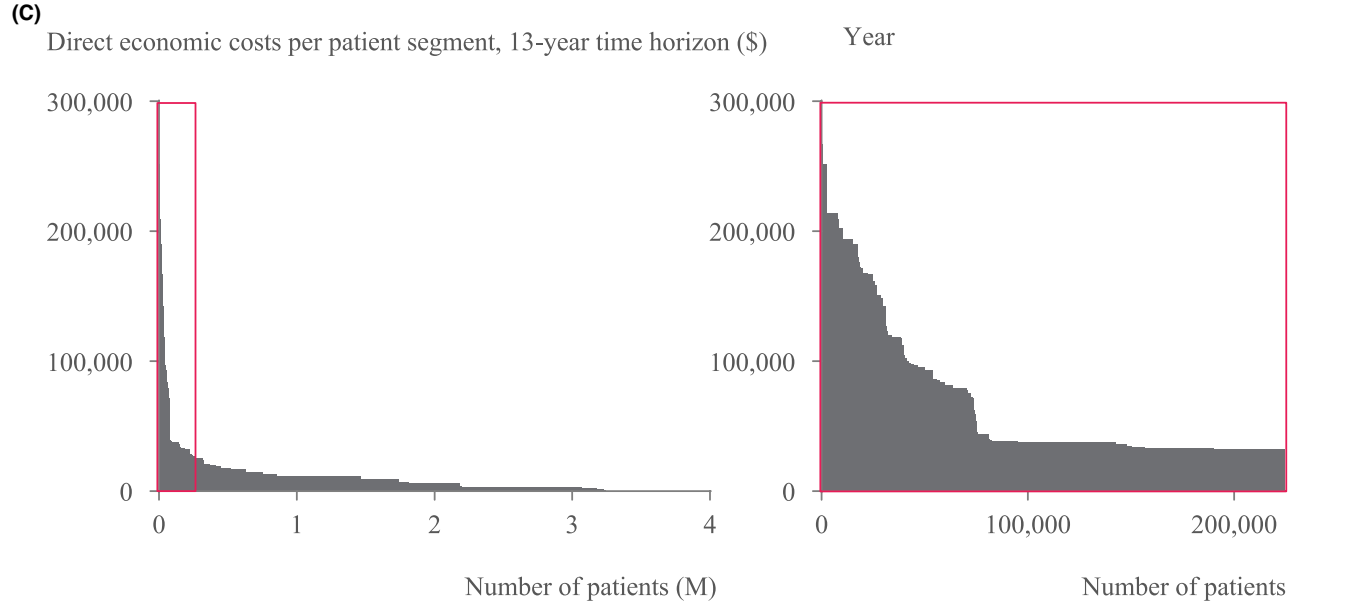
There are four broad approaches to quantifying the benefits of a treatment: (1) direct economic costs that a payer avoids when a patient uses a treatment rather than hospital services; (2) improvements in quality and/or duration of life, for example, QALYs or DALYs; (3) indirect economic benefits to society, for example, GDP growth and additional tax revenue; and (4) monetizing the qualitative patient benefits of treatment. Here, we assume that payers are incentivized entirely by managing direct economic costs. The direct economic value of avoiding hospital costs varies significantly by country, owing to initial disease burden, progression and new incidence and the varying hospital costs of hepatitis C disease management across stages (eTable 2). In the USA, as in other countries, costs grow substantially with disease stage (Figure 1A). In early disease stages, particularly fibrotic stages 0 through 3 and non-decompensated cirrhosis, annual non-treatment costs are low ($3648 in 2018 for the USA; discounted at 3% per annum). As the disease progresses, annual non-treatment costs grow substantially, including for decompensated cirrhosis ($28 086), hepatocellular carcinoma ($44 808), patients receiving a liver transplant ($177 848) and patients treated after liver transplant ($40 487). For a sample population of newly chronic F0 males aged 30–35—the average age of HCV incidence in the USA is 33.6, and males are more likely to become infected than females[11]—expected costs accumulate to >$90 000 over time, and gradually shift from earlier to later disease stages (Figure 1B). Annual non-treatment costs for the UK and Italy are substantially lower (eTable 2), but still exhibit the ~50X difference between least and most expensive hospital costs over time. In addition to the difference in hospital costs between stages of the disease, hospital costs vary by many other dimensions, including fibrotic stage, age and sex, for all countries modelled.

To characterize the direct hospital costs across patients, we computed the annual costs of 2880 unique patient segments, defined by initial disease stage (8 segments), ending disease stage (10 segments), initial age (18 groups from 0–5 to 85+ years of age, in 5-year increments) and sex (2). Sorted by magnitude, the hospital costs form an incremental cost avoidance curve (Figure 1C). When the consumer is a payer whose only optimization criterion is cost minimization, this curve is equivalent to a classical demand curve for the treatment. The incremental cost avoidance from treating early stages of HCV is significantly lower than the 2018 price of curative treatment (~$34 000 for DAA after rebates in the USA), so payers are disincentivized to screen for and treat patients who have not progressed. We thus demonstrate two challenges with the current pricing model: (1) a misalignment between price demanded and value delivered, most easily visible in the systemic payer disincentive to treat low-cost early-stage patients, and (2) a misalignment between upfront payment timing and value delivered over an extended time.

FIGURE 1 Direct economic costs of HCV management. The expected direct economic cost avoidance (A) is the sum of hospitalization costs, discounted at 3% annually, for managing HCV in a patient cohort over a 40-year time horizon beginning in the indicated initial disease stage for a cohort of 30–35-year-old males. Annual cost profiles reflect the costs per number of patients still living in that year. For example, HCC costs per living patient decline slowly with time owing to discounting; however, the overall sum of costs to manage patients beginning with HCC is $71 K, less than the area under the cost profile, because of the high mortality rate of HCC patients. Year 1 for fibrotic stages F0 to F3 is zero because of the assumption that costs begin to accrue 1 year after diagnosis in early stages. US costs are used as an example for comparison relative to different disease stages, but other countries' costs are directionally similar (eTable 2). Note that y-axis ranges differ to show detail. Costs are also shown by disease stages for males aged 30–35 beginning at stage F0 (B). The direct economic costs per patient in the USA, based on the current HCV epidemiology, and summed over the next 13-year period with 3% discounting of costs, is plotted for every patient segment, with a width equivalent to the number of patients in that segment, and sorted by cost (C). For example, males aged 55–59 with decompensated cirrhosis incur hospitalization costs of $161 174 per patient and number 1159 patients in the USA. Inset shows detail for segments with costs greater than $30 000. DC, decompensated cirrhosis; F0–F4, (fibrotic stages 0 to 4); HCC, hepatocellular carcinoma; LT, liver transplant


(A)
Initial disease stage
Expected direct economic cost avoidance
Per living patient, per year ($ K)
Sum ($ K)
F0
F1
F2
F3
F4
DC
HCC
LT
96
108
134
166
229
525
71
594
Time horizon (years)


(B)
Annual cost per patient ($)
Sum of costs per patient ($)
100,000
50,000
Chronic HCV (F0)
F1
F2
F3
Cirrhosis - F4
Decompensated Cirrhosis
HCC
Liver Transplant
Sum of costs
Year


(C)
Direct economic costs per patient segment, 13-year time horizon ($)
Number of patients (M)
Number of patients

3.2 | Historical (2014–2017) scenarios and epidemiological impact of PLA

We first asked what the impact could have been if the PLA model were employed when DAAs were first launched in late 2013 in the USA and 2014 in Europe. We modelled historical epidemiology, costs and revenues for three scenarios:

- "Pre-DAA," where DAAs were not launched
- "SQ," where DAAs were priced and prescribed as in history
- "PLA," where DAAs were priced alternatively using a PLA model

We modelled from launch to the end of 2017.

Historically, the launch of highly efficacious DAAs brought a step change impact in the fight against the HCV epidemic. In our model of the USA from 2014 to 2017, the number of patients treated (880 000 vs. 157 000; Figure 2A,D) and cured (787 000 vs. 91 000; Figure 2B,E) in the "SQ" scenario increased dramatically versus the "Pre-DAA" scenario. However, had the alternative PLA model been implemented upfront, more than double the number of patients would have been treated (1 915 000; Figure 2A,D) and cured (1 603 000; Figure 2B,E) by the end of 2017. The number of liver-related deaths (LRDs) is a lagging indicator of successful treatment expansion; however, PLA still would have significantly reduced the number of LRDs (84 000) versus "SQ" (116 000) and "Pre-DAA" scenarios (136 000; Figure 2C,F).

The launch of highly efficacious DAAs had a dramatic impact on patient outcomes in later fibrotic stages; however, the impact under PLA would have been greater across all fibrotic stages. In the "pre-DAA" scenario, overall HCV prevalence by the end of 2017 in the USA would have been 2.77 M people, with very few cured (Figure 2G). DAAs enabled a substantial reduction in overall prevalence, particularly in late fibrotic stages (2.46 M by 2017; Figure 2H), with a substantial increase in the number of cured patients versus pre-DAA (790 000 vs. 90 000; Figure 2J). Meanwhile, under PLA, DAAs would have reduced HCV prevalence significantly more across all fibrotic stages (to 1.70 M people by 2017; Figure 2I), with more cures versus the "SQ" scenario (1 600 000 vs. 790 000 Figure 2K). In other countries, the proportions of cured and prevalence by fibrotic stage differ owing to varying disease burden and system differences, but PLA would have been more successful as well (eTable 3). The number of cured patients would have increased by 6X in Italy (78% in PLA vs. 14% in SQ) and 4X in the UK (48% vs. 13%), and the number of LRDs would have reduced by 3X in Italy (6.9% vs. 2.2%) and by 2X in the UK (1.6% vs. 0.8%).

3.3 | Future (2018–2030) scenarios and epidemiological and economic impact of PLA

We next asked whether the window of opportunity to impact HCV prevalence has closed. We modelled three scenarios:

- "SQ," where DAAs are priced and prescribed as they have been historically, without change to screening volume
- "WHO," where DAAs are priced as they have been historically, and screening and treatment is increased to meet or exceed WHO targets for diagnosis and prevalence
- "PLA," where DAAs are priced using PLA, and screening and treatment is increased to meet or exceed WHO targets for diagnosis and prevalence

We modelled from 2018 to 2030 because (1) several Netflix-like payment models were beginning to be implemented in 2018, and (2) the WHO HCV elimination target is 2030, and because the first of the novel DAAs (sofosbuvir) loses exclusivity in late 2030.

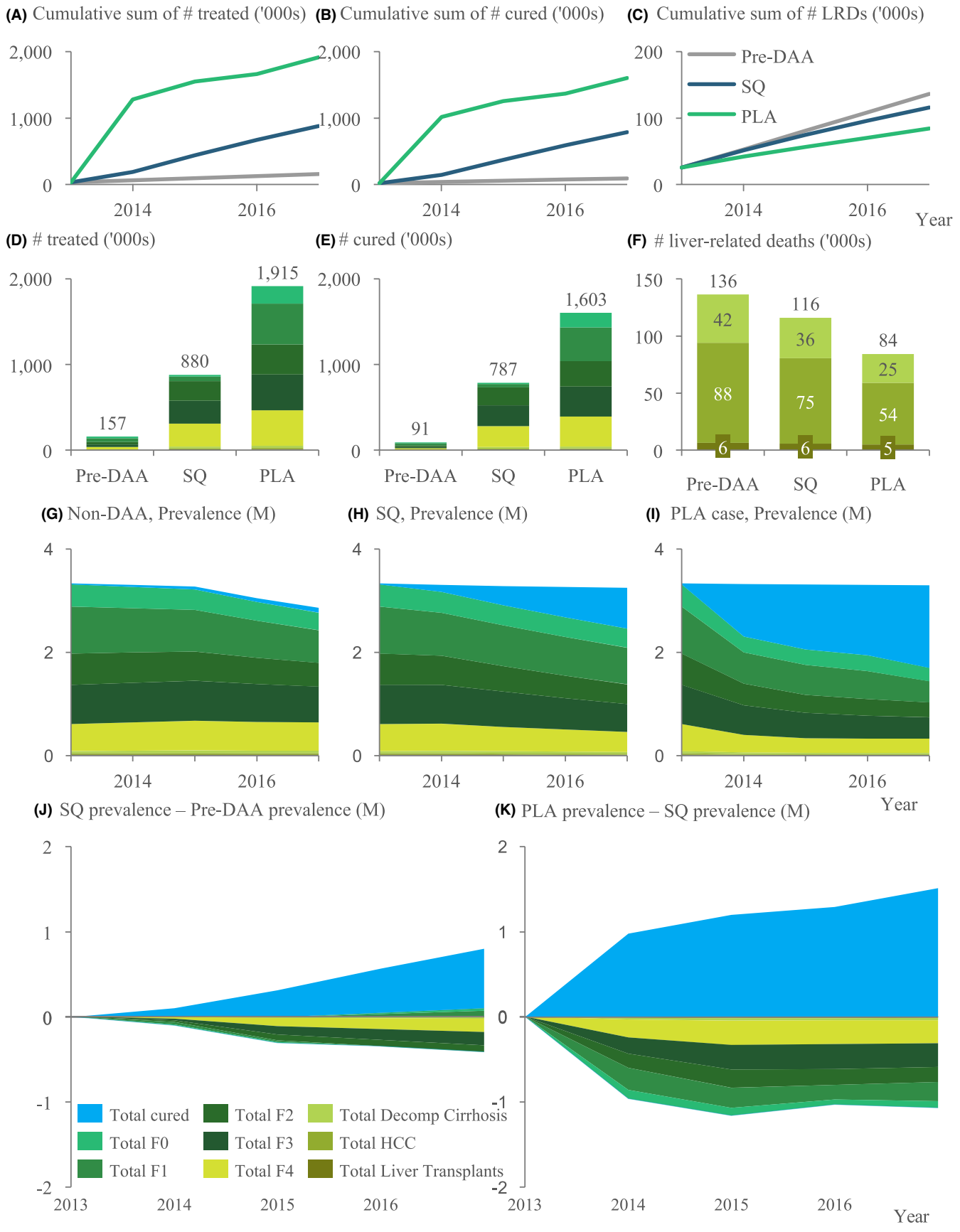
3.3.1 | Epidemiological outcomes under future scenarios

Increasing treatment substantially increased the number of cured patients, reduced number of LRDs and reduced prevalence across all disease stages (Figure 3). PLA reduces prevalence (Figure 3A) and LRDs (Figure 3D), increases patients treated (Figure 3B) and cured (Figure 3C), faster than WHO and both are faster than SQ. In its first year of deployment, PLA would more than quadruple the number of patients treated and cured versus SQ and WHO scenarios in the USA (1.04 M, 0.25 M and 0.18 M treated in PLA, WHO and SQ respectively; Figure 3B; 0.99 M, 0.24 M 0.17 M cured in PLA, WHO and SQ respectively; Figure 3C). By 2030 in the USA, 1.3 M patients will be treated under SQ, while almost double, 2.2 M and 2.4 M, will be treated under WHO and PLA respectively (Figure 3E). The number of cured patients follows the same trend (1.2 M, 2.1 M and 2.3 M cured for SQ, WHO and PLA respectively; Figure 3F).

Meanwhile, LRDs are reduced by 56% in PLA versus SQ in the USA (140 000, 124 000 and 61 000 for SQ, WHO and PLA respectively; Figure 3G). Additionally, among liver transplant patients, PLA results in 29% of the LRDs versus SQ (1471 of 4992, Figure 3G) and similar for WHO.

HCV prevalence across disease stages over time also differs greatly among scenarios in the USA. The WHO scenario results

FIGURE 2 Epidemiological impact of implementing PLA at DAA launch in the USA. The cumulative sum of the number of treated (A), cured (B) and liver-related deaths (LRDs, C) are shown annually from the years 2013 to 2017 by scenario. The total number of treated (D), cured (E) and LRDs (F) for the period of 2014–2017 are shown by disease stage. The annual prevalence by disease stage and cumulative number of cured HCV patients are shown for each of the scenarios Pre-DAA (G), SQ (H), PLA (I). The difference in prevalence by disease stage from 2013 to 2017 is shown comparing SQ less Pre-DAA prevalence (J) and PLA less SQ prevalence (K). For example, in K about 1 M incrementally more cured HCV patients (blue) result from employing PLA versus status quo. HCC, hepatocellular carcinoma



in more cures and lower prevalence versus SQ across all disease stages through 2030, particularly after 2022; PLA improves on WHO (Figure 3H-K). PLA results in significantly more cures and lower disease prevalence in the first 5 years versus WHO, and a sustained difference in the total number of cured patients (Figure 3L).

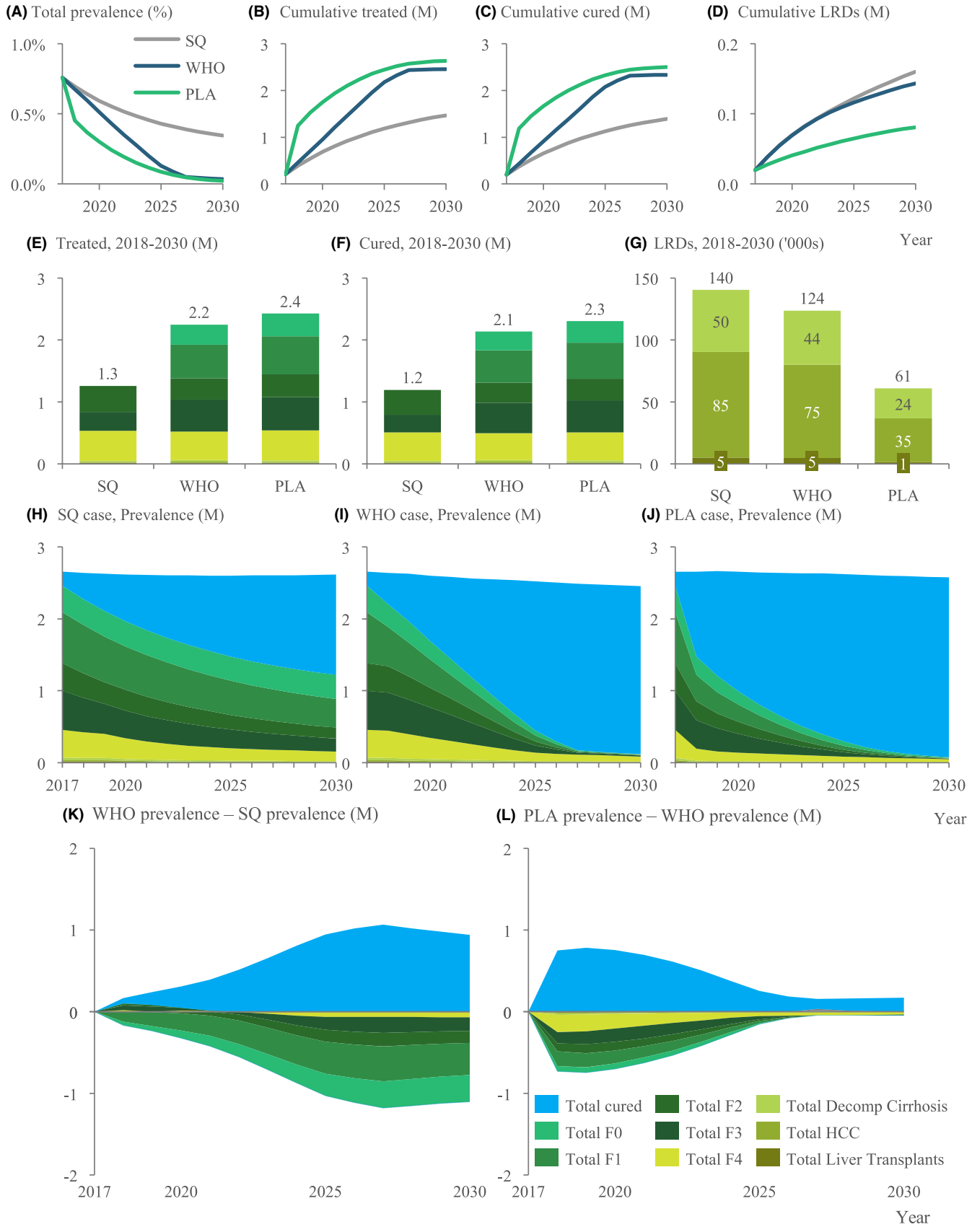


FIGURE 3 Epidemiological impact of implementing PLA in 2018 in the USA. The total prevalence (A), cumulative sum of the number of treated (B), cured (C) and LRDs (D) are shown annually from the years 2018 to 2030 by scenario. The total number of treated (E), cured (F) and LRDs (G) for the period of 2018–2030 are shown by disease stage. The annual prevalence by disease stage and cumulative number of cured HCV patients are shown for each of the scenarios for SQ (H), WHO (I) and PLA (J). The difference in prevalence by disease stage from 2018 to 2030 is shown comparing SQ less WHO prevalence (K) and PLA less WHO prevalence (L). For example, in L employing PLA cures about 750 000 incrementally more HCV patients (blue) than WHO by 2018

Italy and the UK show similar outcomes to the USA: by 2025, the UK would cure 97% of its infected population under PLA (vs. 63% under WHO) and Italy would cure 78% (vs. 32%). Meanwhile, LRDs would drop by at least 4X in both countries (Italy, 64 K vs. 16 K and in the UK 3.4 K vs. 0.7 K, for WHO vs. PLA respectively; eTable 4). Taken together, the PLA shows a substantial increase in the number of patients cured and a decrease in the number of LRDs when compared with both the SQ and the WHO cases, in all countries examined.

3.3.2 | Economic outcomes under future scenarios

PLA resulted in a significant reduction in total hospital (non-treatment) costs, including healthcare provider infrastructure and procedures associated with disease progression (e.g., liver transplantation), plus HCV screening. Through 2025 in the USA, both SQ and WHO scenarios result in similar total hospital costs, while PLA costs are halved ($37.6 B, $37.5 B and $15.8 B, for SQ, WHO and PLA cases respectively; Figure 4A).

To evaluate the revenue and profit implications for treatment manufacturers, we assumed unit pricing based on industry forecasts; for the USA, the rebated price was $34 000 in 2018 (about 40% of $84 000 typical DAA list price) discounted 3% annually thereafter. To compute the revenue associated with the PLA model, we assigned a 10% markup to the total forecasted 13-year SQ revenue ($37.7 B and $41.5 B for SQ and PLA respectively), then distributed this revenue in uniform annuitized payments across the full period. The cumulative cost of treatment was greatest for WHO, with SQ and PLA far lower (Figure 4B). Screening costs were greater for WHO and PLA than for SQ ($3.3 B, $2.7 B and $1.8 B respectively), because of the greater number of screens necessary to achieve the test-and-treat strategy for WHO and PLA (Figure 4C). The total payer cost burden for each of the scenarios varies over time: SQ and WHO sustain the largest upfront cost burden, while the PLA burden is smoother through the period to 2030 (Figure 4D).

The summed economic impact on both payers and manufacturers through 2030 is most favourable under PLA (Figure 4E). Under status quo, payers spend $89.6 B in total costs (treatment, hospital costs and screening), of which manufacturers earn $37.7 B (42%). Under WHO, payers spend $115.7 B, of which manufacturers earn $68.0 B (59%). Importantly, this budgetary increase in treatment costs (80% more than SQ) is not feasible for payers based on current funding constraints. Meanwhile, PLA results in the lowest total payer cost of $66.1 B (a 26% decrease from SQ). Manufacturers' revenue grows to $41.5 B, a 10% increase versus SQ (Figure 4E).

To ensure that the large upfront manufacture and distribution of HCV treatment under PLA does not reduce gross profits, we modelled the impact of unit costs. Unit cost was assumed to be $102 per full DAA treatment in 2018, with 3% discounting thereafter, based on a previous assessment of HCV treatment manufacturing costs.[30] Total COGS was a small proportion of revenue in all scenarios in the USA: $113 M (0.30%), $204 M (0.30%) and $232 M (0.56%) for SQ, WHO and PLA, respectively, resulting in contribution margins of greater than 99% for all scenarios (Figure 4F).

In Italy and the UK, PLA also reduced hospital costs and increased manufacturer revenues (eTable 5). For Italy, total system costs under PLA were reduced to 51% of those under SQ, with hospitalization costs reduced by 68%, while manufacturer contribution margins increased by 8 points. For the UK, the total system costs under PLA remained roughly the same, though hospitalization costs reduced by 59% and manufacturer contribution margins increased by 10 points. The economic benefit of significantly reduced hospitalization costs in the UK did not translate to significant overall cost savings in the UK because hospitalization costs represent only 12% ($646 M of $5455 M) of the total costs of HCV management in SQ (eTable 5).

These economic and epidemiological results are robust against deviations in inputs. Total healthcare costs in all scenarios are most impacted by annual follow-up costs of compensated cirrhosis (eFigure 1A–C). Similarly, the number of people infected with HCV in 2025 are robust against changes in incidence factor, disease stage transition probabilities and advanced stage mortality ratios (eFigure 1D–F). Monte Carlo simulation of a range of inputs confirms that PLA is favourable over WHO and SQ economically and epidemiologically (eFigures 2 and 3).

3.3.3 | Cost-effectiveness

Incremental cost-effectiveness measures are often used to make treatment access decisions, particularly in single-payer countries. Thus, we examined the QALYs saved for WHO and PLA versus SQ. Cumulative QALYs saved versus SQ grows monotonically over time in both scenarios, but PLA significantly outperforms WHO, reaching a maximum QALY difference of +936 000 in 2026 (Figure 5A). The time horizon-dependent ICER[31] indicates a large difference between the two scenarios (Figure 5B). The WHO ICER reaches $200 K/QALY by 2025, after much of the initial disease burden is addressed, and by 2028 reaches $100 K/QALY (Figure 5B). Meanwhile, because the incremental total cost to the payer is negative versus SQ, the PLA is cost-saving throughout the lifetime of the licence, converging to -$18 K by 2030. The incremental cost-savings highlights that the main advantage of PLA is the model structure, which better aligns economic incentives for the payer, manufacturer and patients, and not a different price point.

One retort to PLA is that manufacturers could simply reduce the unit price of treatment to out-compete a PLA. Thus, we modelled the total cost per scenario while varying the unit price that manufacturers would be willing to capture from all treatment sales through 2030 (Figure 5C). Under SQ, manufacturers would need to reduce revenue by $23.5 B (from $37.7 B to $14.2 B, a 62% reduction in weighted-average unit price and thus in revenue) to match payer costs achieved under PLA. Under WHO, manufacturers would need to sacrifice $49.6 B (from $68.0 B to $18.4 B), a 73% reduction, to match payer costs under PLA. PLA clearly outperforms unit-based

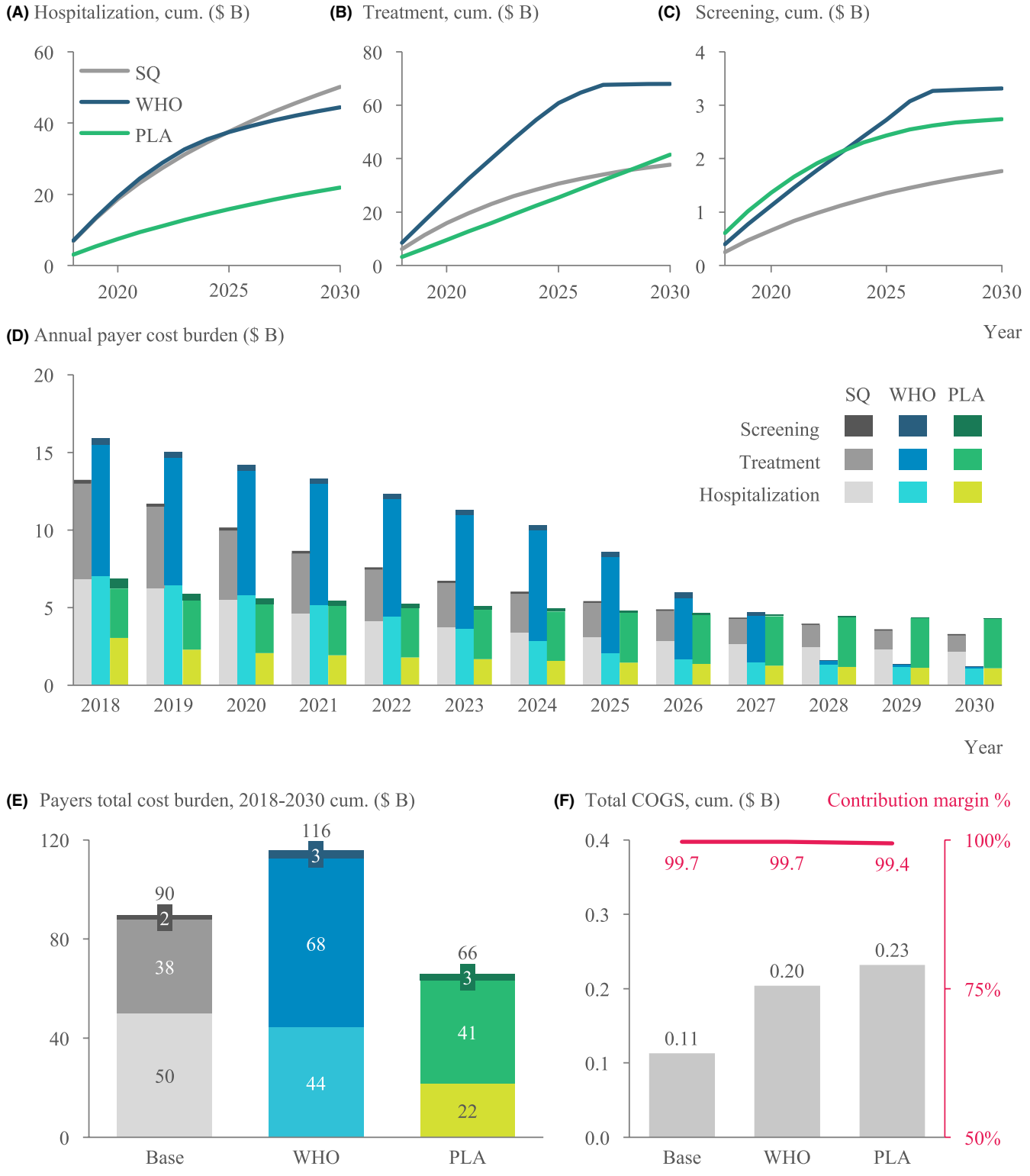


FIGURE 4 Economic impact of implementing PLA in 2018 in the USA. The cumulative sum of costs for hospitalization (A), treatment with DAAs (B) and screening with both anti-HCV and RNA diagnostics (C) are shown annually from 2018 to 2030 by scenario. The annual cost burden to the payer for hospitalization, treatment and screening are compared across scenarios for the PLA licence years 2018–2030 (D) and summed (E). By comparison, the total unit costs (COGS) and resulting contribution margin are shown by scenario in (F)

pricing for the three key variables of cost-effectiveness, total payer cost and manufacturer revenue. Optimizing for the lowest cost per QALY saved and the lowest total payer costs while improving manufacturer revenue strongly suggests implementing PLA.

4 | DISCUSSION

We have shown that applying a PLA pricing model to HCV would result in a "win-win-win" solution: universal patient access to

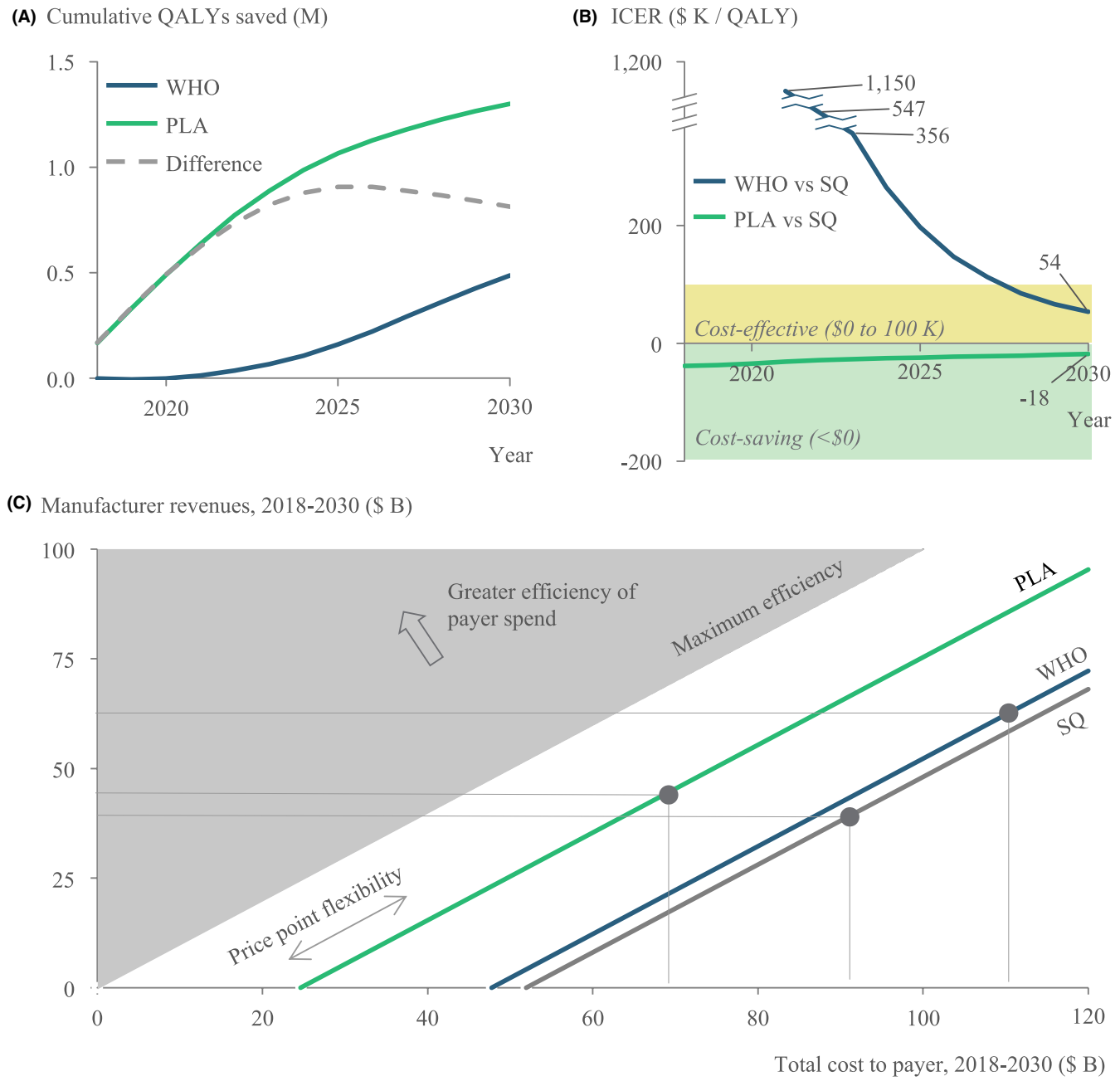


FIGURE 5 Efficiency of payer spend to increase QALYs saved in the USA. Quality-adjusted life years (QALYs) saved in WHO (blue) and PLA (green) versus SQ scenario is shown for the years 2018–2030 (A). The difference (PLA—WHO, dotted line) indicates the net QALYs saved by employing PLA instead of WHO. The time horizon-based incremental cost-efficiency ratio (ICER) is a measure of all incremental costs of the scenario (PLA or WHO versus SQ) divided by all QALY savings (again, PLA or WHO versus SQ) incurred through the year plotted (B); for example, by 2025, WHO (blue) is $197 K/QALY while PLA (green) is -$24 K (cost-saving). ICERs for WHO are not shown in 2018 to 2020 because the denominator (QALY change vs. SQ) is negligible, and are shown with y-axis breaks for 2021 and 2022 given their magnitude. Treatment manufacturers' revenues versus payers' total costs are shown by scenario (C). Reducing treatment pricing (y-axis) reduces total costs (x-axis) along each line defined by the economics of each scenario (SQ, grey; WHO, blue; PLA, green). The maximum efficiency (dotted line) possible represents a payer whose costs are entirely treatment-based, that is, the payer has no hospitalization or screening costs

treatment with disease eradication far faster than status quo, at lower system cost and with greater stability to manufacturer revenue, across a range of high-income countries. The PLA model outcomes are not sensitive to baseline prevalence: the three countries in this study had a five-fold difference in baseline prevalence (0.37% in the UK to 1.76% in Italy) but all showed significant economic and clinical benefit versus SQ. Also, a Monte Carlo simulation revealed minimal sensitivity to any single parameter (tornado plots in eFigure 2C). In addition to the model's insensitivity to baseline prevalence and the incremental

benefit for each stakeholder, several corollary advantages support implementing PLAs. First, our narrow definition of treatment value, direct budgetary costs avoided, is most consistent with payers' reimbursement and access decision criterion. But governments will likely also benefit from GDP output or tax revenue increases, which could be used to subsidize future PLAs. Second, PLAs align incentives more directly among critical stakeholders. Pharmaceutical companies are more incentivized to develop treatments with the greatest incremental value; payers are more incentivized to screen and treat patients when there is no incremental cost to treatment. A portion of payer savings could be used to fund test-and-treat programs, for example, with direct patient payments for screening. Third, PLA could provide an access strategy for health systems with discretionary spend earmarked for epidemics but historically unable to pay high unit costs, such as China's catastrophic medical insurance.[32] Finally, PLAs are highly flexible in implementation, and can be adapted to the relevant disease burden and context. While we have demonstrated the approach with a patient segmentation based on age, sex and disease stage across country-wide populations, many smaller segmentations exist. For example, prison populations have significantly higher HCV prevalence rates and an outsized impact on HCV incidence in the general population; thus, a PLA exclusively for prison populations could have an even greater return on investment for single-payers, as in Louisiana.[7]

Four challenges exist for implementing PLA; none is insurmountable. First, while single-payer systems would realize the near-term cost accounting benefit of PLA, some payers in multi-payer systems would not. For example, US payers' average patient attrition lifetime is <3 years, typically too short a period to realize the cost benefit, and often have separate business units to manage medical and drug expenditures, rendering cross-business cost-saving actions more cumbersome. Structural disincentives to treat patients are beyond the scope of this paper.Second, greater access to treatment could require near-term changes to the healthcare ecosystem, including scaling up manufacturing and supply chain volumes by pharmaceutical companies, and increasing the screening programs and care delivery infrastructure by payers and providers. These costs and risks can be priced in to negotiated PLA annual fees, with conditions for achieving scaled volumes in certain time horizons. Critically, PLA better aligns the incentives of the payers with those of the pharmaceutical industry and patients to rapidly treat as many patients as possible in order to take full advantage of the PLA time period.

Third, poorly conceived PLA contracts could reduce competition among pharmaceutical companies and payer access to innovation. PLAs share the value created so that payers can reduce the total costs of treatment, and manufacturers can fund future innovation. To be successful, payers should negotiate upfront triggers, and potentially buy-out conditions, in the case of new competitive entrants, if the launch of a new therapy provides incremental value over the current standard of care. If late-stage clinical studies, which are public data, suggest a competitive launch is imminent, payers can consider paying a premium in exchange for a shorter PLA contract that preserves the payer's future option to purchase a competitive therapy.

Finally, in situations where more than one pharmaceutical company has an active PLA contract for treating overlapping patient segments, data on prescription volumes may be necessary to adjudicate contracts. This challenge will be a general issue for payer, and the pharmaceutical industry as alternative pricing models, including outcomes-based, indication-based and line of therapy-dependent, will rely increasingly on accurate data to measure and enforce contracts. Historically in other industries, agreed-to data estimations and true-up mechanisms, combined with growing data availability, have addressed these challenges.

The current study has some limitations. First, the costs of implementing an HCV elimination program can vary; elimination programs need to be evaluated programmatically with line-item cost granularity to assess efficiency. Second, while low- and middle-income countries (LMICs) are not the focus of this study, the economics of the PLA work in principle in any health landscape with large hospital costs for untreated patients. Subsequent work should determine the conditions under which LMICs could participate successfully in PLAs.

How does the PLA model compare with real world results to date? In 2016, Australia implemented a version of the PLA for HCV treatment, which has achieved between 20%[8] and 25%[33] reduction in prevalence in the first 24 months. By comparison, prevalence reduction in our modelled countries is 47%–54% in the first 2 years. The difference (22–34 points) likely results from (1) disparities in HCV epidemiology by country, (2) the size of incremental investment in patient awareness and screening programs and (3) improved linkage to care and sufficient physician access. Because the marginal cost of additional treatments is zero and the cost-savings of additional patient treatment is positive, health systems are economically incentivized to increase investment in improved infrastructure to expand access. While Australia has taken steps to improve this infrastructure, our model assumes sufficient investment to maximize treatment access. Importantly, even with existing infrastructure investment, Australia's 25% prevalence reduction in 2 years is significantly more than that which was achieved in other countries under traditional unit pricing: by the end of 2015, 2 years after launch of DAA treatment, prevalence reduction was 12% in the USA, 10% in Italy and 3% in the UK.[9]

Because DAAs have been available for several years, some industry analysts claim that "the market has moved on." However, with continued high HCV prevalence rates and prices that limit treatment access, new pricing model solutions could substantially change the outlook for global management of the HCV epidemic. Additionally, as pharmaceutical industry R&D pipelines are expected to produce more cures for other diseases in the coming decade, PLAs could provide a mechanism to manage costs and incentivize innovation while maximizing treatment access for other curative therapies. Establishing this precedent in HCV with pilot PLA programs could ease its implementation for these pipeline candidates and address

ongoing concerns about recouping the high costs of development[34] given the economics of pricing curative therapies[35] for other therapies and disease areas.

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CONFLICT OF INTEREST

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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