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Abstract

In low- and middle-income countries, scaling essential health interventions to achieve health development targets is constrained by the lack of skilled health professionals to deliver services. This paper takes a labor market approach to project future health workforce demand based on an economic model that projects economic growth, demographics, and health coverage, and using health workforce data (1990–2013) for 165 countries from the World Health Organization's Global Health Observatory. The demand projections are compared with the projected growth in health worker supply and health worker "needs" as estimated by the World Health Organization to achieve essential health coverage. The model predicts that by 2030 global demand for health workers will rise to 80 million workers, double the current (2013) stock of health workers. The supply of health workers is expected to reach 65 million over the same period, resulting in a worldwide shortage of 15 million health workers. Growth in the demand for health workers will be highest among upper-middle-income countries, driven by economic growth and population growth and aging, resulting in the largest predicted shortages, which may fuel global competition for skilled health workers. Middle-income countries will face workforce shortages because their demand will exceed supply. By contrast, low-income countries will face low growth in demand and supply, but they will face workforce shortages because their needs will exceed supply and demand. In many low-income countries, demand may stay below projected supply, leading to the paradoxical phenomenon of unemployed ("surplus") health workers in those countries facing acute "needs-based" shortages.

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Global Health Workforce Labor Market Projections for 2030

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Introduction

The Sustainable Development Goals (SDGs) for health and well-being lay out ambitious targets for disease reduction and health equity for 2030, including universal health coverage (UHC) (United Nations General Assembly 2015). Health systems are highly labor intensive, and health workers play a key role in performing or mediating most of the health system functions. Thus, an effective health care delivery system depends on having both the right number and the appropriate mix of health workers, and on ensuring that they have the required means and motivation to perform their assigned functions well (Anand and Bärnighausen 2012).

In many low- and middle-income countries, efforts to scale up health services to achieve UHC and health development goals are confronted by acute shortages and inequitable distribution of skilled health workers that present a binding constraint to delivering essential health services (Scheil-Adlung 2013; Campbell et al., 2015). These countries face a "crisis in human resources for health" that can be described in terms of: (1) availability, which relates to the supply of qualified health workers; (2) distribution, which relates to the recruitment and retention of health workers where they are needed most; and (3) performance, which relates to health worker productivity and the quality of the care they provide (McPake et al., 2013). Multiple conditions contribute to this problem, including inadequate education and training capacity, negative work environments, weak human resources regulatory and management systems, and inadequate financial and non-financial incentives (Chen et al., 2004; Jimba et al., 2010). National policy makers, researchers and international agencies have called attention to this global shortage and maldistribution of the health workforce, and for governments to make concerted efforts to address these challenges in order to achieve UHC (Kinfu et al., 2009; Campbell et al., 2015).

Given the criticality of the health workforce in the health system, and substantial time and resources invested to educate and develop skilled health workers, it is crucial to understand the factors that affect the size of the future health workforce in order to plan appropriately today. Traditional approaches to addressing human resource constraints in the health sector have focused on "needs-based" workforce planning. Such needs-based planning estimates health workforce requirements based on a country's disease burden profile and the scale-up of education and training capacities to increase the supply of health workers to provide those services (Scheffler et al, 2009; Bruckner et al, 2011). In this approach, health workforce density has been found to be associated with decreases in maternal and infant mortality rates (Anand and Barnighausen, 2004; WHO 2006) as well as in the total burden of disease as measured in disability-adjusted life years (DALYs) (Castillo-Laborde, 2011). Using this approach, WHO estimates that a health workforce density of around 4.45 health workers per 1,000 population corresponds to the median level of health workforce density among countries that have achieved, or have come close to achieving, UHC (WHO 2016). Policy makers could then identify the production capacity and associated financing necessary to increase the stock of health workers to meet these health service requirements (Campbell et al., 2015; WHO 2016).

However, this needs-based approach neglects other important factors that influence the size of the health workforce, notably labor market dynamics that are defined by demand and supply interactions (McPake et al, 2013; McPake et al., 2014). It should not be assumed that labor markets always “clear”, in other words that the supply and demand for workers perfectly match. There are a number of reasons for an imbalance between the demand and supply for workers. For example, prices may not adjust easily due to fixed wage rates established by legislative or bureaucratic processes, or tied to civil service schedules that make them relatively insensitive to the numbers of health workers employers either seek to hire or are willing to be employed. Other institutional rigidities, such as regulatory guidelines and trade unions, can also restrict the extent to which the number of workers demanded or supplied responds to price signals. These situations can lead to either a shortage (i.e., quantity demanded exceeds the quantity supplied) or surplus (i.e., quantity demanded falls behind the quantity supplied) of health workers. Further, the number of health workers estimated to be “needed” to achieve the national health goal of UHC may not necessarily coincide with the demand for health workers due to economic capacity and other market conditions in the health system. Countries may also face unemployment among health workers when the supply of health workers exceeds demand generated by the country’s underlying economic capacity to employ them. A labor market analysis will help to identify such mismatch of labor supply and demand, and lead to more effective policy design to address these issues (Araujo et al., 2016).

This study estimates the demand for health workers in 2030 (the year of SDGs achievement) as a function of economic, demographic and health coverage factors based on an economic model. The model assumes no change in technology or organization of health services, and thus projects the demand for health care as if the current system of health care and technology remains in place in 2030. We then compare this demand projection with the supply and the “needs” projections based on WHO SDG threshold density of 4.45 health workers per 1,000 population (WHO 2016), and discuss the potential policy implications of the findings.

Methods

Theoretical framework

The demand for health workers reflects the willingness to pay of the purchasers of health care (e.g. government, private sector firms), which in turn drives the demand for employing health workers in clinics, hospitals, public health centers and other parts of the health system. The demand for health workers is influenced by factors including household income (i.e. the ability of consumers to purchase health services), the fiscal capacity of the government to support the health system and employ public sector workers, demographic and epidemiologic conditions of the population (e.g., aging and burden of disease that determine the relative types of health services consumers want), and the level of health coverage in terms of risk pooling and financial protection available to enable consumers to access and utilize health care in times of need.

The supply of health workers can be defined as the total number of health professionals with the appropriate skills and qualifications who are willing to enter the job market in the health sector and find acceptable jobs. Labor economics predicts that as the level of compensation offered increases, more qualified workers should be willing to become employed as health professionals (WHO, 2012; Andalon and Fields, 2013). In turn, higher wages encourage more students to apply for health professional education, and increase the demand for medical training and eventually the number of skilled professionals available. In a global labor market where workers' skills may be transferable across country boundaries, migration flows also play an important role in determining the supply of health workers within a country. In particular, outflows of health professionals from low and middle income countries to other, more attractive markets offering better compensation have been identified as one of the biggest challenges facing health systems (Chen et al. 2004; Vujicic and Zurn 2006).

Traditional labor economic analyses assume that, in well-functioning labor markets, disequilibrium (i.e., imbalances between demand and supply) is short-lived. A core assumption is that the wage rate is flexible and freely adjusts the incentives to both employers and health workers to influence their employment behavior and preferences such that equilibrium is restored. Figure 1 depicts a static health worker labor market in which employers' demand (D) to employ health workers interacts with the health workers that are available to supply (S^1) their labor to determine the market wage rate (W*) and number of workers (H*) that will be employed. Countries face a binding constraint on the amount of financing available to employ more health workers, and resource constraints are more severe in lower income countries. A shortage of workers obtains, for example, when a wage rate (W^L) is lower than the market optimum (W*), or when the number of workers supplied (H^S) falls below the number demanded (H^D). All else being equal, shortages in this market could be alleviated through: (1) additional compensation to increase wages to W* and attract more workers into the market; and/or (2) increasing the production of workers or import of workers from external markets to shift the supply curve outward (S^2) while keeping wages at W^L.

In reality, markets can fail to "clear" because prices are either not flexible, or demand and/or supply does not readily adjust to price signals. As pointed out by McPake et al. (2014), both types of rigidities are common in the health labor market. The price of labor in the health sector is often not flexible because wages in the public health sector (often the largest employer in many countries) are usually set by legislative processes and tied to civil servant pay scales. Second, health professional associations (especially for physicians) use their bargaining power to restrict labor supply and negotiate set wage rates. Third, the regulation of health services, such as licensing by professional bodies and governmental jurisdictions to ensure quality standards and monitoring, results in additional rigidities in the ability of workers to become employed wherever positions may be available.

Projecting demand

The demand model builds on a previous economic model for projecting physician numbers (Scheffler et al., 2008). We apply a similar theoretical approach, but incorporate factors in addition to economic growth that are expected to influence demand for health workers, including the demographic structure and health coverage. We also use more recent and robust health workforce data, which are the result of concerted efforts by the WHO to gather cross-national data on workforce numbers since 1990. Because the demand model requires rich historical data on health worker densities, separate models for nurses/midwife and all other health professionals could not be estimated; data for these cadres are insufficient to produce demand projections. Thus, we first predicted number of physicians from the demand model, and then apply constant ratios to obtain estimates of nurses/midwives and all other health workers (AOWs) to obtain the total projected number of health workers.

In most health systems, spending on health workforce wages and benefits represents a significant share of total health expenditures (Hernandez et al 2006). Previous studies indicate that overall economic growth as measured by national income is the best predictor of health expenditures, from which the demand for health workers is derived (Cooper et al. 2003; Getzen 1990). In other words, spending on health care tends to increase as overall income increases, which in turn suggests that more workers can be employed to deliver health services (Cooper et al. 2003; Scheffler et al. 2008).

To our knowledge, few have previously projected future health workforce labor market demand. Owing to data requirements, early works largely focus on specific developed countries for which data on health workers are more readily available (e.g. Korch et al. 2012, Basu & Gupta 2004). Leveraging efforts to obtain cross-national and longitudinal data on health workers, Scheffler et al. (2008) were the first to forecast the demand, need, and supply of physicians for 158 countries with suitable data. While notable in the scope of global coverage, their resulting model relied on only one model parameter input—gross national income—to generate projections.

Our demand model expands on previous methods developed by Scheffler et al. (2008). In addition to income (i.e. gross domestic product (GDP) per capita), we include measures for demographic and health coverage patterns that also drive demand for health workers (Getzen 1990; Cooper et al. 2002; Cooper et al., 2003). The size of the population aged 65 or over is used as an indicator of aging, which is known to increase the demand for health services (Cooper et al., 2002). We also include private per capita household out-of-pocket (OOP) spending on medical care as a proxy indicator for the extent of social protection for health care spending. While overall health care spending may trend upward with national income, the portion spent OOP is largely determined by the level of health coverage by health insurance, government subsidies and other forms of risk pooling and financial protection (Newhouse 1977). Less generous health coverage leaves individuals to pay more OOP, which is expected to lower the demand for and use of health services. Thus, we expect higher OOP health spending to be correlated with lower demand for health workers. We exclude additional structural factors affecting the labor market, such as attrition, training capacity, labor regulations, and migration, as these data are largely unavailable across countries or over time.

The following section provides a summary description of the estimation model. A detailed description of the demand projection methodology, model specification choice, and imputation for missing data is provided in Annex A. Due to the missing data problems for nurses/midwives and AOWs, the economic model was used first to predict the demand for physicians. Systematic ratios were then applied to predicted physician densities to estimate the number of nurses/midwives and AOWs.

The economic model specifies physician density (dependent variable) as a function of GDP, OOP and size of the population over 65 years. Given data availability constraints, we include country fixed effects to account for time-invariant unobservable heterogeneity across countries (i.e. differences in baseline characteristics) that cannot otherwise be controlled. To further account for potential endogeneity, all independent variables were lagged to ensure the direction of causality. Lags for up to five years for each predictor were included to allow time for such factors to work through the economy and affect the labor market. A stepwise approach was used to select the specific combination of year lags that maximized the predictive power of each variable. Lagged variables that achieved a minimum one percent level of significance after repeated iteration were kept within the model, resulting in the following optimal model:

(Eq 1) $\ln(\textit{physicians per 1000 population}_{it}) = \beta_0 + \beta_1 * \ln(\textit{GDP per capita}_{it-1}) + \beta_2 * \ln(\textit{GDP per capita}_{it-4}) + \beta_3 * \ln(\textit{GDP per capita}_{it-5}) + \beta_4 * \ln(\textit{OOPPC}_{it-2}) + \beta_5 * \ln(\textit{Pop65}_{it-3}) + \mu_i + \xi_{it}$

where μ_c represents a vector of country fixed effects, ξ_{ct} is the disturbance term, and β coefficients are unknown parameters to be estimated from the model. Quadratic terms for income and health spending indicators to additionally account for nonlinearities were investigated but ultimately excluded due to multicollinearity.

Equation 1 was fit through a generalized linear model (GLM) using a maximum likelihood estimator. GLM was chosen over OLS as a more flexible estimator; sensitivity tests with OLS produced similar results. Estimated coefficients from the regression model were then applied to the future values of each predictor variable to compute the future predicted physician density.

Alternative model specifications were explored, which included different ways in which input parameters could be calculated (e.g. percentage of the population aged 65+, out-of-pocket health spending as a percentage of total health expenditures). To select the appropriate model, the data were split into an initializing data set (data years 1995-2004) and an attesting data set (data years 2005-2013) with which to assess the precision of predicted values resulting from different specifications. The model in Equation 1 yielded predictions with the lowest mean errors.

We conducted two additional sensitivity analyses of the projections of physician demand resulting from the optimal demand model chosen to alternative input parameters. First, we assess the stability of the predictions to alternative estimated future values of GDP per capita. We use alternative estimated real GDP per capita (US$2010) from the Economic Research Service (ERS) International Macroeconomic Data Set published by the United States Department of Agriculture (USDA), available at http://www.ers.usda.gov/data-products/international-macroeconomic-data-set.aspx (Accessed on September 27, 2015). There was a relatively small (9 percent) difference in the total estimated shortages in 2030 based on the two methods (15.6 million with the main method we used, and 17.0 million using USDA numbers).

Second, we examine the possible upper and lower bounds of the predictions older than 65 resulting from high and low future population estimates. Because population is the largest driver of demand in our model, using the high and low variant estimates, we can obtain predicted total health worker deficits that may result from population growth among people older than 65 that is higher and lower than expected, compared to the median estimate that is presented in the main results. These alternative low and high estimates (shown in Annex Figure A1) indicate a tight band for the resulting predicted values.

Projecting supply

The supply of health workers was projected to 2030 using historical data to predict the changes in health worker densities (per 1,000 population) for each country. We assume that the historical growth rate of health workers density for each country will continue into 2030 at the same rate. This assumes that supply growth is exogenous and only trends with time. This assumption may be plausible if the health labor market is relatively rigid, for example, due to the strong influence of professional associations and trade unions in the sector. Given that data are only available beginning from 1990, and that many countries only have a few data points, the growth rate method enables us to obtain projections using minimal empirical data inputs.

We separately estimate physician and nurses/midwives density for each country from time t = {1990, … 2013} using the following equations:

(Eq 2) $\textit{Physicians per 1000 population}_t = \alpha_0 + \alpha_1 * \textit{year}_t + \varepsilon_t$

(Eq 3) $\textit{Nurses/midwives per 1000 population}_t = \beta_0 + \beta_1 * \textit{year}_t + \varepsilon_t$

where ε_t is the random disturbance term and α_0, β_0, α_1 and β_1 are unknown parameters, with the last two parameters representing the linear growth rates to be estimated from the model.

For countries where more than two historical data points are available for physician and nurse/midwife density, the future projections of worker density are predicted based on the model parameter estimates. More than two historical data points were available for physician and nurse/midwife density for 136 and 81 countries, respectively, out of the total of 165 countries in our sample.

For countries with insufficient historical data points or where linear regression prediction yielded implausible values, several alternative approaches were used to estimate future supply (see Annex A for details). Briefly, for 72 and 118 countries, respectively, for physicians and nurses/midwives, the combined region- and income group-specific aggregate median density rate was applied to the most recent data year. In a number of countries where no empirical data for nurses/midwives was available but information on physicians was available, a global ratio of 2.517 nurse/midwives to physicians was applied to obtain the estimate for nurse/midwife density. The ratio multiplier for all other health workers was then similarly applied to obtain an estimate for all other health workers, and the estimates for all three types of health workers summed to obtain the total supply of health workers per country (see Annex A for more details).

We explored alternatively specifying Equations 2 and 3 as log-linear models, which assumes an exponential functional form. The resulting projections from the exponential specification yielded estimates that were magnified compared to those from the linear specification, exaggerating both positive and negative trends. Coupled with the sparse number of data points for many lower income countries, resulting predicted values appeared to be less stable. Within-sample specification tests were also not possible given the data constraints. We therefore adopted the more conservative linear specification.

Data

Country-level data were collated from multiple sources. Historical data on physician and nurse/midwife densities (1990-2013) were obtained from the WHO Global Observatory Health database (WHO no date). Historical and projected total population and population aged 65 and over were obtained from the United Nations Population Division.

We used the World Bank Development Indicator database to retrieve historical (1995 – 2013) GDP per capita (in constant 2011 dollars, purchasing power parity (PPP) values), total health expenditures per capita (in constant 2011 international dollars, PPP values), and the share of health spending OOP (World Bank 2015). Projected real GDP per capita through 2030 were obtained from the analysis carried out by Patrick Huang-Vu Eozenou (see Annex B for details). Historical data on OOP expenditures per capita (1995-2013) were calculated from health expenditure and OOP percentage data. Estimates for future OOP per capita were obtained by projecting the OOP percentage of total health spending from 2014 to 2030 by selecting the models giving the smallest predicted error for each country (see Annex A for details). Projections of future workforce demand were made for 165 countries for which both demand and supply input data were available.

To obtain the estimates for nurses and midwives and all other workers, we use the approach taken by WHO to fill missing data by multiplying the projected physician density for each country by a constant 2.517 ratio of nurses and midwives to physicians based on the WHO Global Observatory data (WHO 2016). This estimation assumes that the production function for health care workers will stay constant and is the same for all countries. To obtain estimates of all other workers, we similarly applied constant multipliers, but did so stratified according to World Bank income groups (high income = 0.373; upper middle income = 0.406; lower middle income = 0.549; low income = 0.595). These ratios were derived by WHO from the current (2013) ratios of nurses and midwives to physicians and multipliers for all other workers (WHO 2016).

Results

Table 1 summarizes the estimated coefficients from the demand model. The income elasticity for physicians per capita is 0.23, which indicates that a 10 percent increase in per capita GDP (lagged 1 year) is correlated with a 2.3 percent increase in physician density. The elasticity of physician density with respect to OOP health expenditures is negative (consistent with our hypothesis) and significant, indicating that a 10 percent increase in OOP expenditures (lagged 2 years) is associated with a 1.0 percent decrease in physician density. In addition, a 10 percent increase in the size of the population aged 65 or older (lagged 3 years) increases physician density by 5.2 percent.

Table 2 presents projected health worker demand, supply, and differences (supply – demand) for 2013 and 2030. The difference between the number demanded and the number supplied is then shown as either shortage (negative) or surplus (positive). These data projections for each country are further stratified according to resulting overall shortage or surplus of health workers (again defined as the difference in supply and demand) and are shown in Tables 3 and 4, respectively, for 2013 and 2030.

Table 2 shows that by 2030, worldwide demand for health workers will increase to 80 million, but only 65 million will be supplied, amounting to a shortage of some 15 million workers. This is over a two-fold increase over the estimated shortage of 7 million workers in 2013. In 2030, the largest shortages are predicted to occur in the East Asia and Pacific (8.3 million), followed by South Asia (3.2 million), Latin America and Caribbean (2.6 million), and Europe and Central Asia (1.2 million). In terms of income groups, the highest level of shortages in 2030 will occur in upper middle income countries, followed by lower-middle income countries. These countries are likely to experience relatively higher rates of economic growth and population aging, which will generate substantial demand for health workers that may not be adequately met by the increase in supply of health workers. In contrast, countries in Sub-Saharan Africa region show a surplus of health worker (0.8 million), indicating that these countries may experience unemployment or under-employment of health workers. Paradoxically, as will be discussed below, this labor surplus in Sub-Saharan Africa will occur in the context where the demand and supply of health workers remain significantly below the WHO SDG threshold of 4.45 workers per 1,000 population needed to achieve UHC.

Table 3 shows that in 2013, 68 countries showed an aggregate shortage of 11.6 million health workers, while 97 countries showed a surplus of 5.0 million. Table 4 shows that by 2030, some 87 countries will experience health worker shortages of 19.3 million, while the surplus of health workers will reduce to 3.8 million workers across 78 countries. The substantial portion of countries exhibiting a surplus of health workers in 2030 suggests that such excesses of workers beyond what employers will demand may fuel global migration of health workforce, especially if the surplus workers have skills profiles that meet the demand from the countries facing health workforce shortage. Otherwise, these surplus workers will add to unemployment in their respective countries.

Table 5 compares the supply projections of health workers with the needs-based projections of the number of health workers required to meet basic health services utilization targets as defined by WHO for the same 165 countries for which we have demand estimates (WHO 2016). By 2030, based on the need-based model, the largest health worker shortage will occur in low and lower middle income countries, particularly in the Sub-Saharan Africa and South Asia regions. Low income countries face a situation in which both the demand and supply curves for predicted health worker densities fall below the WHO need threshold. In these countries, increasing the supply of health workers to the WHO threshold level will not be sustainable via the market alone, since the demand generated in the labor market will not be sufficient to employ higher numbers of health workers.

In summary, trends in the predicted health worker demand, supply and needs by income level are illustrated in Figure 2. Growth in both demand for and supply of health workers is predicted to be the slowest in low income countries, and these are projected to remain significantly below the WHO SDG threshold of 4.45 workers per 1,000. As a result, these low income countries might experience a paradoxical situation in which they face shortage of health workers needed to provide basic health services, yet they will also face unemployed health workers due to the limited national capacity to employ the available supply of workers. Middle income countries are predicted to experience the largest increase in shortages over this time period, reaching 3.7 million workers in lower-middle income countries and 11.9 million workers in upper middle income countries by 2030. Although these countries will generate sufficient demand for health workers that meet and exceed the WHO SDG threshold density, their challenges will be in producing sufficient numbers of qualified health workers to meet projected demand. The model predicts that high income countries would have a relatively balanced growth in both demand and supply of health workers. However, it should be pointed out that the supply projections used in this analysis used only the net increase in the supply of health workers, and did not take into account changes in the attrition and retirement rates of the health workers. Estimates for the European Union that take into account these workforce dynamics suggest that many high income countries will face substantial shortages of health workers by 2020 due to rapid aging of the current stock of health workers if the rate of production is not increased to compensate for anticipated higher exit rates (Buchan et al., 2014).

Policy Implications

Policy makers must allocate resources and set priorities today based on expectations of future need and capacity to support health workers. Our projections of health worker demand show that predicted trends in the labor market will likely enable many countries to employ more health workers, but that the supply of health workers will not keep pace for about half the countries in the world. By 2030, we estimate a demand-based shortage of over 15 million health workers. Labor shortages are predicted to be most severe in middle income countries and for the East Asia and Pacific region, which is anticipated to have a large increase in demand due to relatively more robust economic growth, rapid population growth and aging, and modest social protection for OOP private health spending. The smallest demand-based shortages are predicted for low income countries, and particularly for Sub-Saharan Africa where neither the supply of, nor the demand for, workers is expected to grow substantially.

By contrast, most of the middle and high income countries are expected to produce enough health workers to meet or exceed the needs-based threshold of 4.45 workers per 1,000. The number of health workers demanded in upper middle and high income countries already meets or exceeded the 4.45 health workers per 1,000 population threshold in 2013, and aggregate demand in lower middle income countries is also projected to surpass this need-based threshold by 2030. However, these countries may face challenges in generating sufficient supply of health workers to meet this demand.

In many middle income countries where we predict robust economic growth and aging, demand shortages may arise due to the country's inability to scale the supply of health workers to meet the rapid growth in demand for health care. Since it takes considerable time to educate qualified health professionals, this labor shortage may lead to wage increases that attract workers from elsewhere, often from lower-income countries to higher-income countries, which could exacerbate health worker deficits in the low income sending countries. These challenges may be particularly pronounced in emerging economies where growth in demand will add considerable pressure to produce more health workers of acceptable quality or accept health workers from other countries.

Comparing needs- and demand-based projections underscores the importance of understanding whether the shortage stems from supply or economic demand constraints, or both. In low income countries where supply and demand are both low, there may be neither enough employment capacity nor adequate numbers of health workers to deliver the critical health services necessary to achieve the SDGs. The situation appears to be especially challenging in many of the low income countries, as the numbers of workers projected to be supplied as well as the capacity of the countries to employ them remain well below the WHO SDG threshold of health worker density. However, it should be remembered that the WHO SDG threshold of health worker density is not meant to be taken as an optimal level; there is likely to be considerable scope for improving efficiency of services and productivity of health workers to expand health coverage with fewer numbers of health workers. For example, propagating service delivery models that utilize more lower-skilled cadres (e.g. community health workers, nurses/midwives) may achieve greater coverage for essential primary care services with the same resources used to produce higher skilled but fewer physicians and specialists (WHO 2016).

These analyses suggest that in many countries, economic growth alone will not suffice to meet the health worker needs in many of the low-income countries. It cannot be emphasized enough that the health workforce projections presented in this paper assume *no changes in the technology or efficiency* of the health care delivery system: that there will be no changes in the organization of the health care delivery system, or in worker productivity or technology. Thus, these projections do not account for potential changes in productivity due to the engagement of other types and levels of health workers, such as physician assistants, community health workers, and other categories of workers. The supply projection also does not take into account attrition rates in the existing stock of health workers, and the additional number of workers who will need to be educated and employed in order to replace those who exit from the labor market. We also do not consider international migration of health workers, which will affect the distribution of health workers as workers move from low demand to high demand countries.

The global shortages projected for 2030 may not occur if labor productivity could be increased, for example, through better use of technology, improved skills development and institutional reforms. A major challenge to the international community is to determine what kind of additional investments will be needed not only to increase the number of health workers in those countries facing health workforce shortages, but to achieve greater productivity and efficiency with the limited number of health workers and achieve a more effective distribution and deployment of health workers both within and across countries.

Opportunities exist to bend the trajectory of the number and types of health workers that are available to meet public health goals and the growing demand for health workers. Improvements in health worker productivity supported by technology-driven efficiency gains, changing the skills mix and other cost-savings approaches could potentially lead to fewer health workers needed to provide equivalent levels of health care services. On the other hand, advances in technology could also increase the scope and complexity of health care interventions, and may lead to even greater demand for more and higher skilled health workers. With foresight and equipped with an understanding of the future labor market for health workers, more strategic policies can be developed to improve both the supply and distribution of health workers to achieve both public health goals and address economic forces.

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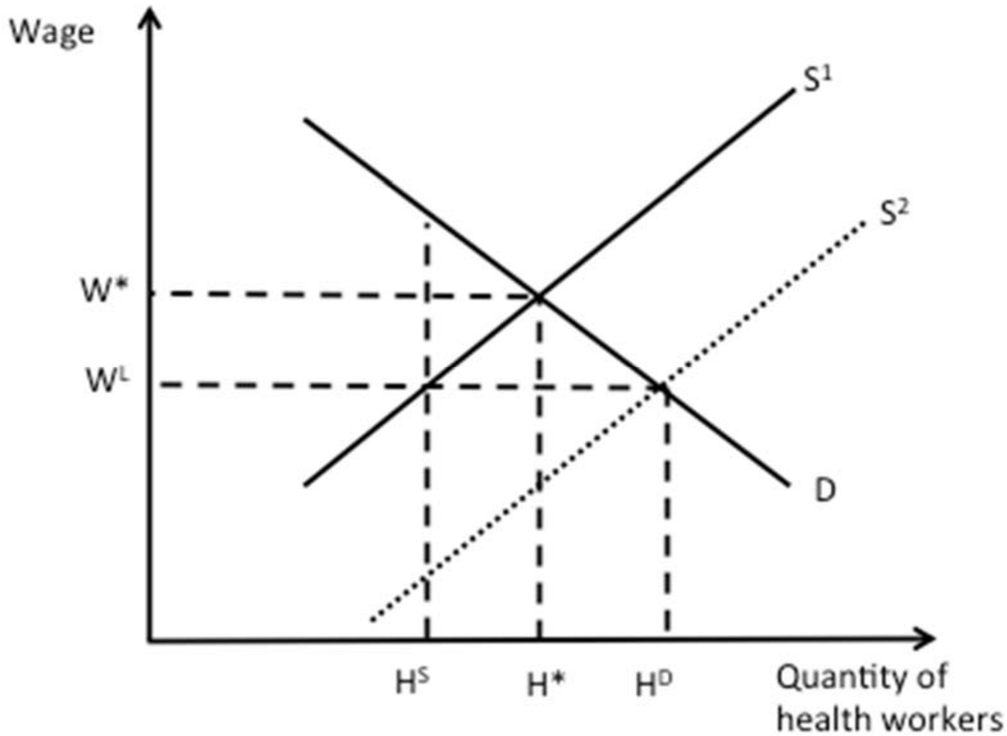
Figure 1. Health worker static labor market theoretical framework



Legend: Demand (D) and supply (S) interact to determine the number of workers (H*) that will be employed at a market wage rate (W*). At a wage rate (W^L) that is lower than the market optimum (W*), a shortage of workers results, and the number of workers demanded (H^D) exceeds the number supplied (H^S). To alleviate shortages in this market, either (1) additional compensation could be given to increase wages to W* and attract more workers into the market, or (2) the production of workers could be increased such that supply shifts outward (S^2) and the quantity demand (H^D) is achieved while keeping wages at W^L.

Figure 2. Trends in demand, supply and need-based number of health workers by World Bank income group, 2013-2030

Legend: Middle-income countries are predicted to experience the largest and most rapidly increasing demand, and subsequent shortages over time period. The average annual growth in the supply of health workers is lower in high and upper-middle income countries than in the lower-middle income countries, but the comparatively higher growth in demand will lead to the largest health worker shortages in the labor market in upper middle-income countries. The growth in the supply for workers is predicted to be the slowest in low-income countries, and the growth in demand is also slower. As a result, the shortage of health workers in low-income countries will double by 2030, but still only amount to 0.3 million health workers. It should be noted that in the low-income countries, both the supply and demand for health workers fall significantly below the threshold level (4.45 health workers per 1,000 population) estimated by WHO (WHO 2016) to be required to meet the basic health care needs.

Table 1.Demand model GLM estimates

	Ln(physicians per 1000)	95% Confidence Interval
Ln(per capita GDP US$2005)$_{t-1}$	0.231***	0.076, 0.387
	(0.079)	
Ln(per capita GDP US$2005)$_{t-4}$	0.531***	0.253, 0.810
	(0.142)	
Ln(per capita GDP US$2005)$_{t-5}$	-0.518***	-0.780. -0.256
	(0.133)	
Ln(per capita OOP health expenditures)$_{t-2}$	-0.099***	-0.144, -0.054
	(0.023)	
Ln(Population age 65 or over)$_{t-3}$	0.516***	0.372, 0.660
	(0.073)	
Constant	-9.882***	-11.47, -8.29
	(0.810)	
Observations	1179	
Country fixed effects	YES	
Log-likelihood	658.1	

Table 2. Estimated global demand and supply of health workers, by WHO/World Bank regions and World Bank income group, 2013 and 2030

	2013 (165 countries)			2030 (165 countries)			# Countries
	Demand	**Supply**	**Need**	**Demand**	**Supply**	**Need**	**in each group**
WHO Region							
Africa	1,106,183	1,874,830	5,891,071	2,404,807	3,066,666	8,910,473	43
Americas	8,826,933	8,385,480	5,439,623	15,288,610	12,742,856	6,246,463	28
Eastern Mediterran	3,057,524	2,690,443	3,797,769	6,201,515	4,611,408	5,055,625	15
Europe	14,178,009	12,692,401	5,628,533	18,158,772	16,803,264	5,786,268	50
South-East Asia	5,964,318	5,772,250	12,433,083	12,206,786	10,168,591	14,712,987	8
Western Pacific	15,133,290	10,294,627	11,538,553	25,894,849	17,261,342	12,270,476	21
WB Region							
East Asia and Pacific	15,481,985	11,141,638	13,692,899	26,546,027	18,250,702	14,734,499	23
Europe and Central Asia	14,007,183	12,594,176	5,578,223	17,844,850	16,640,618	5,722,567	48
Latin America	4,526,235	4,140,233	3,287,004	8,374,987	5,784,767	3,825,876	26
Middle East & North Africa	2,517,001	2,570,885	2,354,695	4,913,419	3,846,948	3,032,910	15
North America	4,300,699	4,245,248	2,152,619	6,913,623	6,958,089	2,420,587	2
South Asia	6,494,350	5,357,579	11,745,586	13,459,980	10,293,688	14,248,390	8
Sub Saharan Africa	938,804	1,660,273	5,917,606	2,102,453	2,879,315	8,997,462	43
WB Income group							
Low	637,584	692,757	4,861,904	1,400,074	1,384,576	7,049,048	29
Lower-middle	10,897,535	9,867,919	17,605,293	21,682,581	17,958,943	21,940,256	44
Upper-middle	19,040,552	13,764,139	14,617,189	33,291,730	21,362,033	15,934,777	46
High	17,690,584	17,385,217	7,644,247	23,780,953	23,948,576	8,058,211	46
World	**48,266,256**	**41,710,032**	**44,728,633**	**80,155,338**	**64,654,127**	**52,982,292**	**165**

Notes: Health worker refers to physicians, nurses/midwives, and other health workers.

[1]Region and income group aggregates are summed for only countries that have a health worker shortage; countries without a shortage are not included.

[2]Demand for nurses/midwives was calculated assuming a ratio of 2.517 nurses/midwives to one physician.

[3]Demand and supply of other health workers was calculated assuming a ratio of 3.517 doctors and nurse/midwives times a World Bank income group-specific multiplier.

[4]Supply of physicians and nurses/midwives was projected based on the country-specific linear growth rates of physicians and nurses per 1,000 population.

Table 3. Estimated global demand and supply of health workers by WHO/World Bank regions and income group, 2013; disaggregated by countries with shortage and surplus (Difference: Supply – Demand).

	Shortage countries					Surplus countries				
	Demand (D)	**Supply (S)**	**Need**	**Difference (S-D)**	**# Countries**	**Demand (D)**	**Supply (S)**	**Need**	**Difference (S-D)**	**# Countries**
WHO Region										
Africa	32,357	20,570	168,664	-11,787	3	1,073,826	1,854,259	5,722,406	780,434	40
Americas	6,612,863	5,111,374	3,872,984	-1,501,490	18	2,214,070	3,274,107	1,566,639	1,060,037	10
Eastern Mediterran	2,325,668	1,511,359	2,576,703	-814,309	9	731,856	1,179,084	1,221,066	447,229	6
Europe	9,432,898	6,916,358	3,504,234	-2,516,540	29	4,745,111	5,776,043	2,124,299	1,030,933	21
South-East Asia	5,542,630	4,847,018	10,129,877	-695,613	3	421,687	925,233	2,303,207	503,546	5
Western Pacific	13,132,605	7,142,858	10,183,203	-5,989,747	6	2,000,685	3,151,769	1,355,351	1,151,084	15
WB Region										
East Asia and Pacific	13,132,605	7,142,858	10,183,203	-5,989,747	6	2,349,380	3,998,780	3,509,697	1,649,400	17
Europe and Central Asia	9,262,072	6,818,133	3,453,923	-2,443,939	27	4,745,111	5,776,043	2,124,299	1,030,933	21
Latin America	2,662,078	1,414,236	1,935,612	-1,247,842	17	1,864,157	2,725,997	1,351,392	861,841	9
Middle East & North Africa	1,617,766	1,177,244	1,160,165	-440,522	9	899,235	1,393,641	1,194,530	494,406	6
North America	3,950,785	3,697,138	1,937,372	-253,647	1	349,914	548,110	215,247	198,196	1
South Asia	6,421,358	5,279,358	11,596,725	-1,142,000	5	72,992	78,221	148,861	5,230	3
Sub Saharan Africa	32,357	20,570	168,664	-11,787	3	906,447	1,639,703	5,748,942	733,256	40
WB Income group										
Low	395,927	223,855	1,699,364	-172,072	5	241,657	468,902	3,162,540	227,245	24
Lower-middle	8,834,452	6,850,983	12,800,744	-1,983,469	17	2,063,083	3,016,936	4,804,549	953,853	27
Upper-middle	15,462,673	8,497,379	10,939,972	-6,965,294	20	3,577,879	5,266,760	3,677,217	1,688,881	26
High	12,385,969	9,977,320	4,995,585	-2,408,649	26	5,304,614	7,407,897	2,648,661	2,103,283	20
World	**37,079,021**	**25,549,537**	**30,435,665**	**-11,529,485**	**68**	**11,187,234**	**16,160,495**	**14,292,968**	**4,973,261**	**97**

Table 4. Estimated global demand and supply of health workers by WHO/World Bank regions and income group, 2030; disaggregated by countries with shortage and surplus (Difference: Supply – Demand).

	Shortage countries					Surplus countries				
	Demand (D)	**Supply (S)**	**Need**	**Difference (S-D)**	**# Countries**	**Demand (D)**	**Supply (S)**	**Need**	**Difference (S-D)**	**# Countries**
WHO Region										
Africa	643,548	453,757	2,423,284	-189,791	13	1,761,259	2,612,909	6,487,188	851,649	30
Americas	5,294,324	2,177,226	2,270,537	-3,117,097	17	9,994,286	10,565,630	3,975,926	571,344	11
Eastern Mediterran	5,735,711	3,976,303	4,248,811	-1,759,408	12	465,804	635,105	806,814	169,301	3
Europe	8,813,848	6,485,872	2,740,579	-2,327,976	32	9,344,924	10,317,392	3,045,689	972,468	18
South-East Asia	11,420,891	9,039,083	12,091,674	-2,381,808	3	785,895	1,129,508	2,621,313	343,613	5
Western Pacific	23,359,616	13,836,069	11,088,037	-9,523,547	10	2,535,233	3,425,273	1,182,439	890,040	11
WB Region										
East Asia and Pacific	23,359,616	13,836,069	11,088,037	-9,523,547	10	3,186,411	4,414,633	3,646,462	1,228,222	13
Europe and Central Asia	8,499,926	6,323,225	2,676,878	-2,176,701	30	9,344,924	10,317,392	3,045,689	972,468	18
Latin America	5,294,324	2,177,226	2,270,537	-3,117,097	17	3,080,663	3,607,541	1,555,339	526,878	9
Middle East & North Africa	4,574,811	3,342,787	2,615,168	-1,232,024	13	338,608	504,161	417,742	165,553	2
North America	0	0	0	0	0	6,913,623	6,958,089	2,420,587	44,466	2
South Asia	13,325,263	10,153,540	14,091,101	-3,171,723	5	134,717	140,148	157,290	5,431	3
Sub Saharan Africa	213,998	135,463	2,121,201	-78,535	12	1,888,455	2,743,852	6,876,260	855,397	31
WB Income group										
Low	1,142,167	787,953	4,149,362	-354,214	14	257,907	596,623	2,899,686	338,716	15
Lower-middle	19,143,815	14,797,698	16,063,131	-4,346,117	23	2,538,766	3,161,245	5,877,124	622,479	21
Upper-middle	28,403,598	15,305,990	12,465,315	-13,097,608	23	4,888,132	6,056,042	3,469,462	1,167,910	23
High	6,578,358	5,076,669	2,185,113	-1,501,689	27	17,202,596	18,871,907	5,873,098	1,669,311	19
World	**55,267,937**	**35,968,311**	**34,862,922**	**-19,299,627**	**87**	**24,887,401**	**28,685,817**	**18,119,370**	**3,798,416**	**78**

Table 5. Estimated global health workforce supply versus "need" as defined by WHO, by WHO and World Bank regions and income group for 2013 and 2013.

	2013 (165 countries)			2030 (165 countries)			# Countries in Category
	Supply (S)	Need (N)	Diff (S-N)	Supply (S)	Need (N)	Diff (S-N)	
<u>WHO Region</u>							
Africa	1,874,830	5,891,071	-4,016,241	3,066,666	8,910,473	-5,843,806	43
Americas	8,385,480	5,439,623	2,945,857	12,742,856	6,246,463	6,496,393	28
Eastern Mediterranean	2,690,443	3,797,769	-1,107,326	4,611,408	5,055,625	-444,217	15
Europe	12,692,401	5,628,533	7,063,868	16,803,264	5,786,268	11,016,996	50
South-East Asia	5,772,250	12,433,083	-6,660,833	10,168,591	14,712,987	-4,544,397	8
Western Pacific	10,294,627	11,538,553	-1,243,926	17,261,342	12,270,476	4,990,867	21
<u>WB Region</u>							
East Asia and Pacific	11,141,638	13,692,899	-2,551,261	18,250,702	14,734,499	3,516,203	23
Europe and Central Asia	12,594,176	5,578,223	7,015,953	16,640,618	5,722,567	10,918,050	48
Latin America	4,140,233	3,287,004	853,229	5,784,767	3,825,876	1,958,892	26
Middle East & North Africa	2,570,885	2,354,695	216,190	3,846,948	3,032,910	814,038	15
North America	4,245,248	2,152,619	2,092,629	6,958,089	2,420,587	4,537,501	2
South Asia	5,357,579	11,745,586	-6,388,007	10,293,688	14,248,390	-3,954,702	8
Sub-Saharan Africa	1,660,273	5,917,606	-4,257,333	2,879,315	8,997,462	-6,118,146	43
<u>WB Income Groups</u>							
Low	692,757	4,861,904	-4,169,147	1,384,576	7,049,048	-5,664,472	29
Lower-middle	9,867,919	17,605,293	-7,737,374	17,958,943	21,940,256	-3,981,313	44
Upper-middle	13,764,139	14,617,189	-853,050	21,362,033	15,934,777	5,427,256	46
High	17,385,217	7,644,247	9,740,970	23,948,576	8,058,211	15,890,364	46
World	**41,710,032**	**44,728,633**	**-3,018,601**	**64,654,127**	**52,982,292**	**11,671,836**	**165**

Annex A: Estimation Method for HRH Demand Projections

A1. Methodological overview

The steps in economic modeling of projected health workforce numbers are described in reference to the illustrative example depicted in Figure A.1. The demand model (D) reflects the number of workers that will be demanded in each country given anticipated economic and demographic conditions. In other words, this is the size of the workforce that a country is likely to be able to afford. We then compare this to the projected supply of health workers based on the historical trend in health workers for each country (S). The surplus or shortage of per capita workers can then be calculated as the difference between what is demanded and what is supplied.

For example in Figure A.1, economic, health spending, and demographic changes may demand only 2.3 health workers per 1,000 population by 2030, represented by the scenario D1. Compared to a projected supply of 3.4 physicians per 1,000 population in 2030 (S), this would represent a surplus of health workers. In a different scenario, future shortages of health workers could occur in the scenario represented by D2 in which the 2.4 health workers per 1,000 demanded in 2015 increases to 4.8 health workers per 1,000 in 2030. This translates into a shortage of 0.45 health worker per 1,000 in 2015, growing to 1.4 health workers per 1,000 in 2030 if nothing is done to actively augment worker supply.

For additional context, Figure A.1 also includes a needs-based (N) estimate that is commonly employed to assess the adequacy of the size of the health care workforce (WHO 2006). The needs-based forecast (N) reflects the number of physicians that would be required to reach a desired benchmark of service utilization (WHO 2006, Scheffler et al. 2013). In our illustrative example, there will be 4.1 health workers per 1,000 population needed to deliver health care services at the desired level of coverage, which corresponds to a shortage of health workers based on the need criterion.

We can then multiply this estimated shortage or surplus by projected population numbers to calculate the absolute deficit or excess number of health workers.

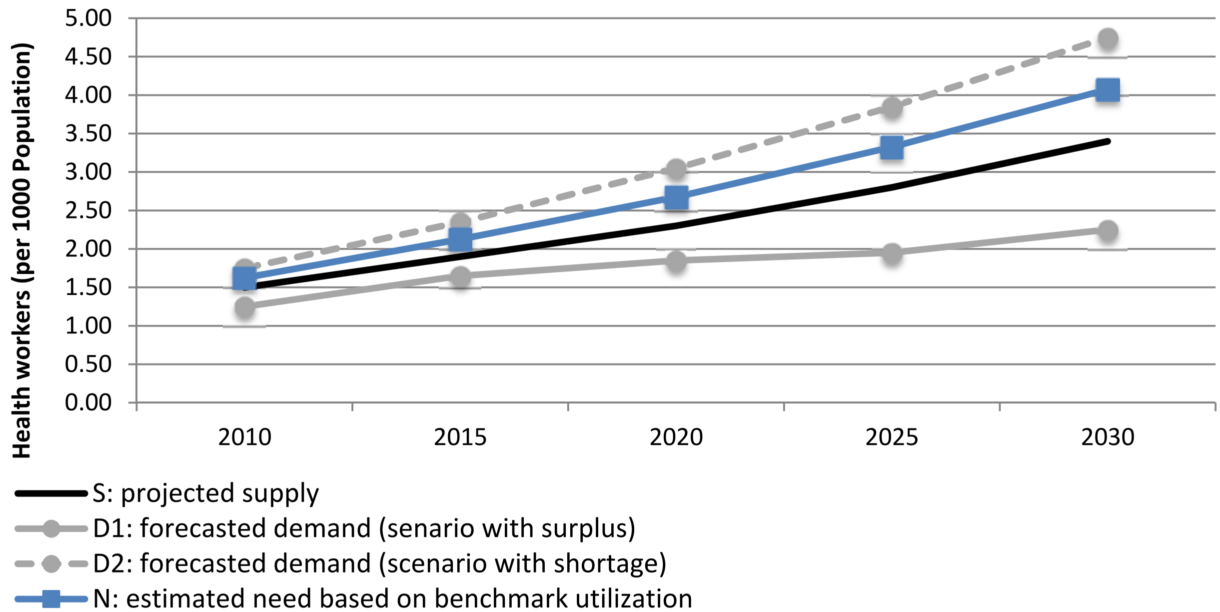
The steps in estimating the future demand and supply of health workers are as follows:

1. Estimate an economic model that predicts the density of physicians (i.e. per 1,000 population) that will be demanded in each country given predicted future growth in income, out-of-pocket (OOP) health expenditures, and size of the population aged 65 or over. A ratio of 2.517 nurses/midwives to physicians is then applied to obtain the number of nurses/midwives. Constant multipliers by income level are then applied to the combined demand densities of physicians and nurses/midwives to obtain estimates of all other health worker demand densities. Projected population size is then used to calculate the corresponding number of workers that will be demanded. The numbers of physicians, nurses/midwives, and all other workers (AOWs) are then summed to obtain

an aggregate estimate of the number of total health workers demanded.

2. Project the future supply of physicians and nurses/midwives per 1,000 population for each country between 2013 and 2030, based on historical trends via a simple linear projection. Constant multipliers by income level are then applied to the combined supply densities of physicians and nurses/midwives to obtain supply density estimates of AOWs. Projected population size is then used to calculate the corresponding numbers of workers of each cadre that could be supplied for each future year.
3. The projected number of total health workers demanded in 2030 is then compared to the number supplied in 2030. A country is deemed to have a shortage of health workers in 2030 if the number of workers demanded exceeds the number supplied. The total number of health workers in countries that are predicted to have a shortage in 2030 are then summed by World Bank region and income level.

Figure A.1 Conceptual framework for projecting health worker labor supply and demand



It is important to note that demand and supply are endogenously related in the labor market. However, we employ different methods to project each that seek to address potential endogeneity. Namely, we purposively employ a linear growth projection model for supply that is based solely on an exogenous time trend. Further, all parameter inputs into the demand model are lagged up to five years to ensure the direction of causality.

A2. Data sources

The data sources used in this exercise are outlined in **Table A1.** All available data points for all countries/territories and years indicated were downloaded and merged together.

Table A1 Data sources

Indicator	Years	Source
Number of physicians and nurse/midwives per 1000 population	1990-2013	WHO Global Health Observatory
Total population, Population aged 65 or over	1980-2030	United Nations, Department of Economic and Social Affairs, Population Division
Real GDP per capita (2011 PPP $)	1995 - 2030	See Annex B, estimation by Patrick Eozenou
Total health expenditures per capita (PPP constant 2011 international $), Percent of total health expenditures spent out-of-pocket	1995-2013	World Development Indicators, extracted from the WHO Global Health Expenditure database

Data on worker density from the WHO Global Health Observatory database for 193 countries were first cleaned to remove obvious outliers due to misreporting. In each of the country-year observations listed in Table A2, outliers were replaced with missing data so that estimated growth rates would not be unduly influenced by arbitrary substitution.

Table A2 Workers per 1000 population data outliers

Country	Years
Bhutan	2012
Saint Lucia	1999
Swaziland	2000
Bahrain	2005, 2011
Bolivia	2001
Cabo Verde	2004
Cameroon	2004
Central African Republic	2004
Congo	1998
Ghana	2004
Guinea-Bissau	2004
Guyana	2004
Micronesia	2009
Samoa	1999
Sierra Leone	2004
Zambia	2004
India	1991

Missing data points for physicians and nurses/midwives per 1,000 population between any two real data points were then linearly interpolated. The resulting data set of physicians and nurses/midwives per 1,000 population that accounts for the data outliers in Table A1 and with interpolated values was used for both worker supply and demand projections.

A3. Demand model estimation and results

Empirical specification

Previous research has shown that indicators of gross domestic product or national income are the best predictors of health expenditures, of which, labor is the principle component (Cooper et al. 2003, Getzen 1990, Newhouse 1977, Plaff 1990). To our knowledge, few have previously projected future health workforce labor market demand. Owing to data requirements, early works largely focus on specific developed countries for which data on health workers are more readily available (e.g. Korch et al. 2012, Basu & Gupta 2004). Leveraging efforts to obtain cross-national and longitudinal data on health workers, Scheffler et al. (2008) were the first to forecast the demand, need, and supply of physicians for 158 countries with suitable data. While notable in the scope of global coverage, their resulting model relied on only one model parameter input—gross national income—to generate projections.

We build directly on this previous work. Our demand model projection utilizes per capita indicators of gross domestic product (GDP), based on purchasing power parity, 2011 constant international US dollars, household out-of-pocket (OOP) health expenditures, as well as the size of the population aged 65 or over as the main predictors. We exclude additional structural factors affecting the labor market, such as attrition, training capacity, labor regulations, and migration, as these data are largely unavailable across countries or over time.

Each variable in our demand model is selected based on the following rationale:

- GDP per capita: Overall economic growth is expected to drive demand for health care with a positive elasticity as a normal good. Indicators of economic growth have been found to determine health worker employment (Cooper et al. 2003) and have previously formed the fundamental building blocks of forecast estimates of physician demand by Scheffler et al. (2008).
- Household OOP health spending is included as a proxy measure of the generosity of health insurance coverage within a given country. As such, we expect higher OOP payments to lower the derived demand for health workers per capita; in other words, less generous coverage leaves individuals to pay more out of pocket. While overall health care spending may trend upward with national income, the portion spent OOP is largely determined by the level of coverage by health insurance, government subsidies, and other forms of risk pooling and financial protection.
- The size of the population aged 65 or over is included as an indicator of the demographic effects of population aging and ensuing demand for health care services utilized at older ages (Cooper et al. 2002). Driven by lower adult mortality, demographic transitions, particularly of rapidly aging populations in large countries, such as China and India, will place additional pressure on health care services for the elderly.

Using historical data on physician densities, GDP per capita, OOP spending per capita, and the size of the population aged 65 or over, we estimated the relationship between the economic and population indicators and physicians per 1,000 population using a generalized linear model (GLM). Missing data points for physicians per 1,000 between any two real data points were linearly interpolated. No adjustments were made where data was missing in projected physician densities.

For countries where historical data for total per capita health expenditures and OOP health spending was completely missing, mean yearly values for the specific World Bank region and income group combination to which the country belonged were substituted (see Annex C, below, *Projecting out-of-pocket expenditures*). No adjustments for missing data were made where data was not available for population or GDP per capita; this data tended to be missing for a handful of very small countries, where the projections would minimally affect overall shortage estimates. Thus, countries for which population or GDP per capita data were not available are excluded from the demand projections.

All variables were transformed into logs. To avoid endogeneity, GDP per capita, OOP spending per capita (OOPPC), and the size of the population aged 65 or over (Pop65) were all lagged up to five years to allow time for such factors to work through the economy and affect the labor market, as other authors have done in previous projection exercises (Getzen 1990; Scheffer et la. 2008). A stepwise approach was used to select the specific combination of year lags that maximized the predictive power of each variable. Lagged variables that achieved a minimum 1% level of significance after repeated iteration were kept within the model, resulting in the following optimal model:

(Eq 1) $$\ln(\textit{physicians per 1000 population}_{it}) = \beta_0 + \beta_1 * \ln(\textit{GDP per capita}_{it-1}) + \beta_2 * \ln(\textit{GDP per capita}_{it-4}) + \beta_3 * \ln(\textit{GDP per capita}_{it-5}) + \beta_4 * \ln(\textit{OOPPC}_{it-2}) + \beta_5 * \ln(\textit{Pop65}_{it-3}) + \mu_i + \xi_{it}$$

where μ_c represents a vector of country fixed effects, ξ_{ct} is the disturbance terms, and β coefficients are unknown parameters to be estimated from the model. Country fixed effects are included to account for time-invariant unobservable heterogeneity across countries (i.e. differences in baseline characteristics between countries). Quadratic terms for income and health spending indicators to additionally account for nonlinearities were investigated but ultimately excluded due to multicollinearity.

Model specification selection

Three alternative specifications for the demand model were checked. Specifically, we examined the stability of the results with the following changes:

1. Using the percentage of the population aged 65+ instead of absolute size of population aged 65+.
2. Using OOPPC as a percentage of total per capita health expenditures in place of OOPPC.
3. Using the percentage of the population aged 65+ and OOPPC as a percentage of total per capita health expenditures in place of their respective absolute number counterparts.

To select the appropriate model, the data set was split into two parts:

1. Initialization data set included data for years 1995 – 2004.
2. Testing data set included data for years 2005 – 2013 (except for log physician densities variable, which was set to missing).

Each model specification was first estimated using the initialization data set, using the lag structure from Equation 1. The estimated parameters were then applied to the actual covariates from the testing data set to obtain predicted values of physician densities for 2005 through 2013. These predicted values were then compared with actual data for physician densities in 2005-2013. To formally assess the fit of each model, we calculate the mean square root of the squared error:

(Eq 2) Mean error = $\frac{1}{CT}\sum\sqrt{(ln(phys\,\widehat{per}\,1000)_{ct} - ln(phys\;per\;1000_{ct})^2}$

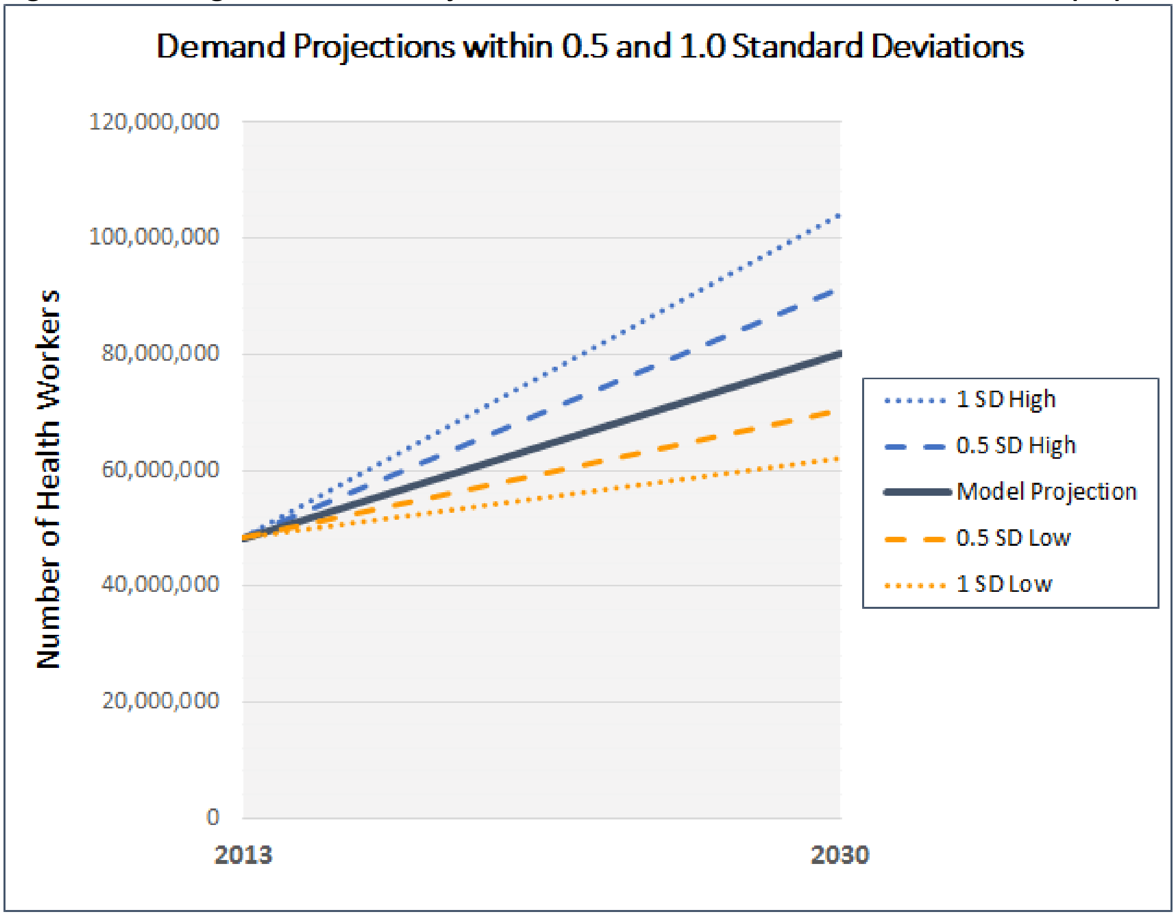
Table A3 summarizes mean errors resulting from different model specification. The optimal model (Eq 1) was found to generate the best predictions in terms of having the lowest mean errors. Therefore, this model was chosen to estimate parameters using full data set (1995-2013). Predicted values of logged physician densities from this model were then transformed with an antilog and multiplied by a correction factor ($e^{\sigma^2/2}$) to account for the skewed distribution. Future values of physicians per 1,000 population were then multiplied by projected total population size (medium fertility assumptions) for each year to obtain the absolute number of physicians.

Table A3 Mean errors for demand projection models

Model	*N=C*T*	Mean	Standard deviation
Eq 1	653	0.2640	0.5640
Alternative 1	653	0.2779	0.5403
Alternative 2	653	0.2649	0.5627
Alternative 3	653	0.2768	0.5322

The range of demand (Eq. 1) projections at 0.5 S.D. and 1.0 S.D. are shown in Figure A.2, below.

Figure A.2 Range of Demand Projections within 0.5 and 1.0 Standard Deviation (SD)



Because the demand model requires rich historical data on health worker densities, separate models for nurses/midwife and all other health professionals could not be estimated; data for these cadres are insufficient to produce demand projections. To obtain the estimates for nurses/midwives, we multiply the projected number of physicians demanded for each country by 2.517, the ratio of nurses/midwives to physicians accepted as a global benchmark (WHO 2016). By using this constant ratio, we assume that the production function for health care workers in terms of skills mix stays constant. To obtain estimates of all other workers (AOWs), we apply constant multipliers according to World Bank income level (high income = 0.373; upper middle income = 0.406; lower middle income = 0.549; low income = 0.595) according to the following formula for each country of a given income classification:

(Eq 3) *AOWs per 1000 population* = *multiplier* * [(2.517* *physicians per 1000 population*) + *physicians per 1000 population*]

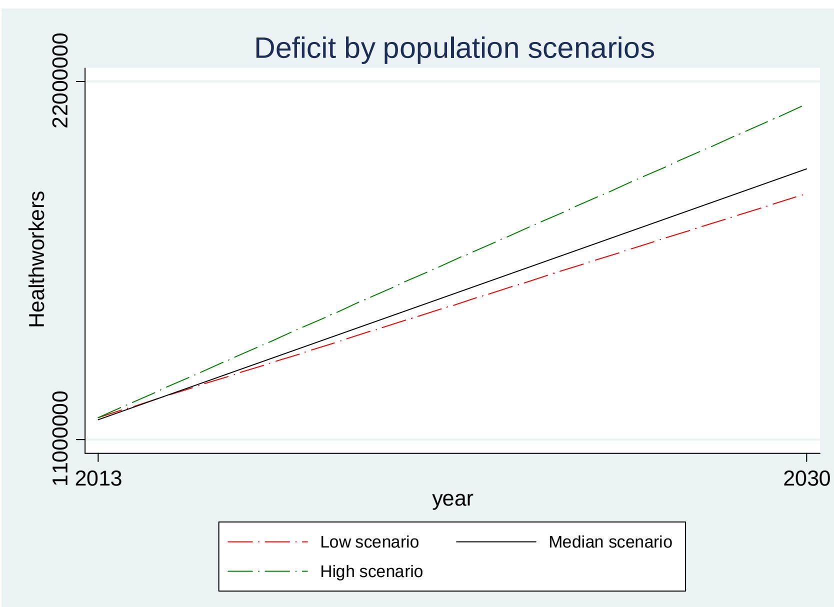
Demand model sensitivity analyses

We conducted two additional sensitivity analyses of the projections of physician demand resulting from the optimal demand model chosen to alternative input parameters.

First, we assess the stability of the predictions to alternative estimated future values of GDP per capita. We use alternative estimated real GDP per capita (US$2010) from the Economic Research Service (ERS) International Macroeconomic Data Set published by the United States Department of Agriculture (USDA), available at http://www.ers.usda.gov/data-products/international-macroeconomic-data-set.aspx (Accessed on September 27, 2015). There was a relatively small (9 percent) difference in the total estimated shortages in 2030 based on the two methods (15.6 million with the main method we used, and 17.0 million using USDA numbers)

Second, we examine the possible upper and lower bounds of the predictions older than 65 resulting from high and low future population estimates. Because population is the largest driver of demand in our model, using the high and low variant estimates, we can obtain predicted total health worker deficits that may result from population growth among people older than 65 that is higher and lower than expected, compared to the median estimate that is presented in the main results. These alternative low and high estimates are shown in Figure A3 below, indicating a rather tight band for the resulting predicted values.

Figure A3. Projected total health worker deficit using low and high projections for the size of the population older than 65



Note: where the predicted demand was less than the predicted supply, the estimated deficit was assumed to be zero.

A4. Supply model

The supply of physicians and nurses/midwives can be projected to 2030 based on historical data on the increase in physician and nurse/midwives densities (i.e. per 1,000 population) in each country. Yearly health workforce density data since 1990 are available from the WHO Global Health Observatory database. We extract all available data points for physicians and nurses/midwives.

Various econometric approaches can be used to project supply numbers, each with advantages and disadvantages as described in Table A.4. Of the three types of econometric approaches, th growth rate method is the simplest, most straightforward, and requires the least amount of data, but may be less accurate given stronger functional form assumptions. Other methods rely less on the functional form assumption, but require more data points. A moving average or distributed lag model (2) which gives more weight to more recent data requires that data be available for a continuous number of years, and an ARIMA (autoregressive integrated moving average) model (3) requires that a long time series be available (i.e. ideally back to 1980) with very few missing data points. Given the availability of the health worker data, we chose to proceed with the growth rate model, which has previously been employed in health worker projections (Scheffler et al. 2008).

Table A.4 Econometric modeling approaches for projecting supply

Model	**Advantages**	**Disadvantages**
1. Growth rate	• Simple and straightforward • Only need 2 data points minimum per country	Potentially less accurate if inappropriate functional form
2. Moving average/ distributed lag	• Gives more weight to recent data • Relies less on functional form assumptions	Requires that the workforce numbers be populated for at least some number of continuous years
3. ARIMA	• Can account for cyclical fluctuations • Relies less on functional form assumptions	Need data for a longer time period (back to 1980) with very few missing observations.

This growth model assumes that current trends in the growth of physician numbers will continue as they have historically for each country. Using the growth rate approach, we explored two functional forms:

1. Exponential (i.e. log-linear)

   (Eq 4a) $\ln(\textit{Physicians per 1000 population}_t) = \alpha_0 + \alpha_1 * year_t + \varepsilon_t$

(Eq 4b) ln(*Nurses/midwives per 1000 population*$_t$l = $\beta_0 + \beta_1 * year_t + \varepsilon_t$

2. Linear

   (Eq 5a) ln(*Physicians per 1000 population*$_t$) = $\alpha_0 + \alpha_1 * year_t + \varepsilon_t$

   (Eq 5b) ln(*Nurses/midwives per 1000 population*$_t$l = $\beta_0 + \beta_1 * year_t + \varepsilon_t$

Equations 4 and 5 were estimated for each country from time t = {1990, … 2013} where ε_t is the random disturbance term and α_0, β_0, α_1 and β_1 are unknown parameters, with the last two parameters representing the growth rates to be estimated from the model.

Comparing the resulting projections between these functional forms revealed at the exponential specification yielded estimates that appeared to be magnified (and potentially unrealistic) compared to a linear specification. Coupled with the sparse number of data points for many lower income countries, resulting predicted values appeared to be less stable. Within-sample specification tests were also not possible given the data constraints. We therefore adopted the more conservative linear specification based on a *status quo* scenario which assumes the supply growth is exogenous and only trends with time following the historic trends. This scenario also implies a relatively rigid labor market, which may be plausible for the health labor market that is dominated by strong professional associations.

Equation 5 was estimated for each country, and for physicians and nurses/midwives separately. We then applied the following rules to predict future (2014 – 2030) values of worker densities:

a. Where at least two data points were available, we extended the estimated linear trend into the future, until 2030 using the estimated coefficients for α and β.
b. If the estimated linear growth was found to be too large or too small, the country's growth rate was replaced with aggregate medians, and then the median growth rate was applied to the last available observation for that country (i.e. most recent year).
   i. For physicians: If a given country's linear growth rate was larger or smaller than 1 standard deviation from the mean growth rate for all countries, the region-income group specific median growth rate was substituted.
   ii. For nurses/midwives: For nurses, there was large over-dispersion of the linear growth rate distribution. Consequently, if a country's linear growth rate was larger than 80% or smaller than 20% of the growth rate distribution, then the WB income group specific median growth rate was substituted.[1]
   iii. For both physicians and nurse/midwives: If the predicted density in 2030 resulted in a negative number, these country's growth rate was also replaced with the corresponding median aggregate value.
c. If there was just one point for a country (and thus linear growth rate could not be

[1] Note, because the empirical data for nurses/midwives have more missing data, growth rates could be estimated from the historical trend for comparatively fewer numbers of countries. A higher level of aggregation is needed (i.e. income level, rather than region and income level) to obtain suitable median substitution values across a sufficient number of countries within the grouping.

estimated), we applied the same median substitution for the growth rate as described in 2b.

d. When no observations were available before 2013 (i.e. no empirical data at all for both physicians and nurses/midwives), neither the physician nor nurse/midwives supply was projected. Instead, the mean 2030 predicted supply density across countries of the same income level was substituted.

e. In certain cases, special treatment was given to particular countries because of data problems or predicted growth rates or densities that were implausible.
   i. Dominican Republic: The physician growth rate was replaced with the median value.
   ii. Greece: The nurse/midwife growth rate was applied to the 2000 density value (rather than the 2001 value).
   iii. Chile: The nurse/midwife growth rate resulted in excessively large predictions; the growth rate was reset to 0.0001/year to reflect a stable trend.
   iv. Haiti: There was only one historical data point for nurses/midwives. The median income value that would be applied was negative, which resulted in predicted densities near zero; the growth rate was reset to 0.0001/year to reflect a stable trend.
   v. Gambia and Kenya: The estimate growth rates were negative, leading to predicted densities near zero; the group median growth rate was substituted.

f. In a number of countries, no empirical data for nurses/midwives were available, but information on physicians was available. We therefore applied to global ratio of 2.517 nurse/midwife-to-physician ratio to obtain the estimate for nurse/midwife density. The countries affected are: Iraq, Slovak Republic, Bosnia and Herzegovina, Serbia, and Macedonia.

These various substitutions and the number of countries affected are summarized in Table A5.

Table A5. Summary of methods used to predicting future worker supply

		Method for addressing missing data				
	Total N	**a**	**b**	**d**	**e**	**f**
Physicians						
Supply	208*	136	50	21	1	0
Demand	165	120	44	0	1	0
Nurses/midwives						
Supply	208*	81	100	19	3	5
Demand	165	73	84	0	3	5

* Note that although 201 countries are included in the analysis, 2030 supply predictions are only made for 208 countries. Kosovo and St. Martin (French part) are excluded from the projections because they do not have population estimates for 2030.

The projected supply of physicians and nurses/midwives per 1,000 population for each future year was then multiplied by projected population (medium fertility assumptions) in that year to obtain the absolute numbers of physicians and nurses/midwives. The formula is as follows:

(Eq 6) *Number of workers = worker per 1000 population * population in 2030*/1000

To obtain estimates for the other cadres, we apply the standardized approach adopted by the team and which was previously applied to the need-based worker estimates. The income group-specific multiplier[2] was multiplied with a constant ratio of 3.517 and the physician density, according to the following formulas according to the method applied by WHO (2016):

High income	Other cadres per 1000 = 0.373 * (3.517) * physicians per 1000
Upper middle income	Other cadres per 1000 = 0.406 * (3.517) * physicians per 1000
Lower middle income	Other cadres per 1000 = 0.549 * (3.517) * physicians per 1000
Low income	Other cadres per 1000 = 0.595 * (3.517) * physicians per 1000

The resulting density of other cadres was then multiplied by population size (see Eq 15) to obtain the absolute number of workers in other cadres.

A5. Calculating worker surplus or shortages

The surplus or shortage of workers for each country *c* and year *t* is calculated as the difference between what is demanded what is supplied:

(Eq 7) $\textit{Difference (Surplus/Shortage)}_{ct} = \textit{Workers supplied}_{ct} - \textit{Workers demanded}_{ct}$

A6. Aggregation by region and income level

We report projected health worker demand, supply, and shortage estimates by regions and income levels as defined by the World Bank (see data.worldbank.org/about/country-and-lending-groups).

Demand projections were only made for 165 countries for which sufficient data for input parameters were available. In reporting aggregate shortages, we only include countries for which there is a projected demand-based shortage in 2013 or in 2030. In other words, countries that are estimated to have health worker surpluses in 2013 or in 2030 are not counted toward shortage totals in respective years (i.e. a zero shortage is assumed). This is consistent with the assumption that there are no transnational movements of workers (i.e. shortages and surpluses do not net out across countries), following the approach of WHO (2006).

[2] The multiplier was determined via a separate methodology within the needs-based worker threshold analysis (WHO 2016).

Annex B: Estimation of GDP Projections to 2030[3]

Estimation Method

- Data from 1995 to 2020 are obtained from the World Economic Outlook database.
- Data from 2014 to 2020 are IMF estimates.
- Data from 2020 to 2035 are projections based on the following assumptions:
  1. Cobb-Douglas production function with constant returns to scale: Y = A*K^(1-alpha)*L^(alpha)
  2. Labor share (alpha) = 1/3
  3. TFP growth (A) and Capital growth (K) are constant at steady state
  4. Labor force growth is equal to population growth
  5. Data on population growth are taken from the UN-DESA World Population Prospects 2012 (medium fertility assumption)

Steps

1. Derive the projections for annual growth rates of real GDP --> (World Economic Outlook data base (WEO_NGDP_RPCH)
2. Rebase the WDI constant GDP series (2011 GDP deflator = 100) in LCU --> WDI_GDP_constant_LCU2011
3. Derive the projections for real GDP at 2011 prices using projected growth rates (2021-2035) to real GDP estimates from 2020 onward --> REAL GDP PER CAPITA
4. Apply WPP 2012 population projections based on medium fertility assumption to derive projected real GDP per capita (expressed in million LCU per capita) --> REAL GDP PER CAPITA
5. 2011 PPP factors are applied to convert constant GDP in LCU to international $ --> REAL GDP PER CAPITA
6. A multilevel model with country and region random effects is estimated to derive GNI projections from GDP projections --> REAL GNI PER CAPITA

[3] GDP estimation for 2030 was prepared by Patrick Eozenou (Health Economist, World Bank) for the working paper by Olusoji Adeyi, Caroline Ly, Patrick Eozenou, Allyala Nandakumar, Ariel Pablos-Mendez and Timothy Evans, "The economic transition of health in Africa: a call for progressive pragmatism to shape the future of health financing".

Annex C: Projecting out-of-pocket expenditures

Future values of OOP spending per capita are needed as input parameters into the demand model projections to predict future values of physicians per 1,000 population. Based on historical data for total health expenditures per capita (PPP constant 2011 international $) and the percentage of total health expenditures spent OOP, we calculate the OOP health expenditures per capita for each country from 1995 to 2013 based on the following formula for each country *c* in year *t*:

(Eq 8) $OOPPC_{ct} = \%\ \text{total health expenditures spent } OOP_{ct} * \text{Total health expenditure per capita}_{ct}$

For 27 countries where health expenditure information was completely missing, year-specific mean OOP spending per capita by region and income group were substituted. These countries were as follows: American Samoa, Aruba, Bermuda, Cayman Islands, Channel Islands, Curacao, Faeroe Islands, French Polynesia, Greenland, Guam, Hong Kong SAR, China, Isle of Man, Democratic People's Republic of Korea, Kosovo, Liechtenstein, Macao, New Caledonia, Northern Mariana, Puerto Rico, Sint Maarten, Somalia, St. Martin, Taiwan, China, Turks and Caicos, Virgin Islands, West Bank and Gaza, and Zimbabwe.

To select the appropriate model, the data was split into two parts:

1. Initialization data set included data for years 1995 – 2008.
2. Testing data set included data for years 2009 – 2013 (except for OOPPC variable, which was set to missing).

To project future values of OOP spending per capita, we tested eight models with the initialization data set:

1) For each country *c*, a moving average for 18 prior periods without weights was estimated:

(Eq 9) $OOPPC_{ct} = \frac{1}{18}\sum_{x=1}^{18} OOPPC_{c,t-x}$

A total of 18 previous periods was chosen to maximize the number of prior year observations possible to base projections off of (e.g. the projection for 2030 needs at least 17 lags to use prior information from 2013).

2) For each country *c*, a moving average for 14 prior periods with weights was estimated, with the more distant observations progressively receiving smaller weights:

(Eq 10) $OOPPC_{ct} = \frac{1}{171}\sum_{x=1}^{18}(18 - x) OOPPC_{c,t-x}$

3) For each country *c*, double-exponential smoothing over 14 prior periods was applied:

(Eq 11) $S_{ct}^{[2]} = \alpha S_{ct} + (1-\alpha)S_{c,t-1}^{[2]}$,

where $S_{ct}^{[2]}$ is the smoothed original series from $S_{ct} = \alpha X_{ct} + (1-\alpha)S_{c,t-1}$, and α is the smoothing parameter estimated by minimizes the in-sample sum-of-squared predicted errors; X_{ct} is the original series.

4) For each country *c*, we estimated the following regression where β represents the yearly difference in OOPPC over the previous year, and ε_{ct} is a random error term:

(Eq 12) $OOPPC_{ct} = \alpha + \beta Year\ trend_{ct} + \varepsilon_{ct}$

5) For each country *c*, we estimated the following regression that additionally accounts for non-linearities in the time trend of OOP:

(Eq 13) $OOPPC_{ct} = \alpha + \beta_1 Year\ trend_{ct} + \beta_2 (Year\ trend_{ct})^2 + \varepsilon_{ct}$

6) For all countries *c*, we estimated the following pooled regression that includes country fixed effects (γ_c) as well as a flexible time trend:

(Eq 14) $OOPPC_{ct} = \alpha_c + \beta_1 Year\ trend_{ct} + \beta_2 (Year\ trend_{ct})^2 + \gamma_c + \varepsilon_{ct}$

7) For all countries *c*, we estimated the following pooled regression that includes three dummy indicators for World Bank (W_r) income group classifications as well as a flexible time trend:

(Eq 15) $OOPPC_{crt} = \alpha_r + \beta_1 Year\ trend_{crt} + \beta_2 (Year\ trend_{crt})^2 + \sum_{r=1}^{4} W_r\ \delta_r + \varepsilon_{ct}$

8) The same regression for Equation 9, but correcting for AR1 serial correlation.

The estimated parameters were then applied to the testing data set to obtain predicted values for 2009 through 2013. These predicted values were then compared with actual data in 2009-2013. To assess the fit of each model, we again calculate the mean square root of the squared error, displayed in Table C.1.

(Eq 16) Mean error = $\frac{1}{CT}\sum\sqrt{(\widehat{OOPPC}_{ct} - OOPPC_{ct})^2}$

Table C.1 Mean errors for out-of-pocket health spending projection models

Model	*N=C*T*	Mean	Standard deviation
1	1075	104.7602	120.2658
2	1075	87.52218	101.3041
3	1070	41.89035	77.43136
4	1075	218.3716	173.5767
5	1075	225.382	166.4547
6	1075	100.8074	81.81804
7	1040	147.0227	134.1653
8	1075	94.51554	76.15938
9	1075	44.60224	58.05829

Models 2 and 3 (Table C.1) were found to have the smallest prediction error among the first eight. Moreover, we average the predictions resulting from Methods 2 and 3, which can improve prediction accuracy (Makridakis et al., 2008). To further improve prediction accuracy, we have selected the optimal method (i.e. which minimizes the square root of the squared error) for each country, rather than across all observations. Thus, for example, method 9 may minimize prediction errors in country A, but weighted average may minimize error in country B. Rather than force one method on all countries uniformly, we have allowed the optimal model selection to be country-specific. This indeed has led to further substantial reduction in the average prediction error across all observations (with mean squared error now being 22.0), and therefore this is our preferred approach.

The predicted values for *OOPPC* were then used as inputs into the overall demand model. In six countries (Brunei, Burundi, Cote d'Ivoire, Lebanon, Qatar, Serbia), the OOPPC projection using the combined method yield predicted values below zero for certain future years. For these countries, estimates from Model 2 alone were used as the projected values.