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RESEARCH ARTICLE

Out-of-pocket health payments: a catalyst for agricultural productivity growth, but with potentially impoverishing effects in Senegal

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Abstract This paper analyzes the relationship between health expenditures and productivity in Senegal by using a dynamic recursive computable general equilibrium (CGE) model that has been run from 2011 to 2020. This model links the growth rate of agricultural productivity to household investment in health goods taking into account catastrophic health payments considered as barriers to achieve maximal productivity gains. In fact, despite being a potential catalyst for productivity, out-of-pocket health expenditures can be a burden after a critical threshold has been crossed and might potentially decrease household resources and place constraints on the productivity-generating process. Results show a positive impact on poverty reduction when the Government reduces the burden on households by financing catastrophic payment overshoots. Lower health costs also appear to improve households' well-being, especially in the case of agricultural households. These results suggest the need for policies which will reduce the health system's reliance on out-of-pocket payments and demonstrate that health programs should reach the most vulnerable households. The effectiveness of poverty-orientated interventions can be increased by targeting households incurring catastrophic health expenditures.

Keywords Agricultural productivity · Health · Poverty · Out-of-pocket health expenditures · Senegal

JEL classifications Q12 · I130 · I320

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Introduction

Agriculture is an important sector in Senegal and the main economic activity in rural areas (60 % of the population, World Bank 2011) and comprises a large share of total employment (more than 45 %, ANSD 2013). The sector is affected by a continuing decline in exports and food supply as a result of productivity loss partly attributed to the poor rainy season and factors related to mismanagement and political considerations. In many African countries, the poverty reduction objective is accompanied by a set of initiatives and reforms concerning fiscal management and budget allocation (CAADP, MTEF, Program-Budget, etc.)[1] in order to deal with the institutional failure and the weakness of budgetary processes. The Senegalese government has undertaken numerous reforms and activities in response to the global productivity decline in order to generate a higher economic growth rate. Despite being widely recognized that agriculture can play a crucial role in poverty alleviation in African countries, governments continue to invest less in this sector. Therefore, it is important to consider how to promote non-agricultural sectoral policies with strong spillover and externality effects on agriculture. Indeed, in a context of limited resources, a budget allocation process integrating direct as well as indirect effects across the economy can help increase policies' impact without necessarily relying on large financial resources. A better orientation and an efficient allocation of the resources can ensure linkage and consistency between social sector budget allocation and achievement of certain sets of agricultural development goals.

Human capital theory supports the view that people with greater health stock should have higher labor productivity

[1] CAADP: Comprehensive Africa Agriculture Development Programme
MTEF: Medium-Term Expenditure Framework

thanks to the positive effects on physical and mental capacity, i.e., endurance and strength of workers. The loss of productivity can also be due to the change in time allocation by integrating time needed to care for sick family members (Asenso-Okyere et al. 2011).

Out-of-pocket health payments have an impact on household health and, in return, on welfare and productivity as earlier underlined in the Grossman theory of demand for health care. However, there is evidence that beyond a certain threshold these expenditures can become a burden when they account for a large share of household budget. In fact, out-of-pocket health payments might increase agricultural productivity, but when catastrophic, they can lead to households' impoverishment by lowering their disposable income and by constraining them to sell their assets in order to afford medical goods and necessary services. In Senegal, household out-of-pocket payments represent the primary source through which health expenditures are made, namely, 95 % of private expenditures and 55 % of the total expenditures (GIP SPSI 2006). However, there is almost no insurance coverage in the informal sector and the coverage rate remains low in the formal sector, with only 10 % of the workers concerned (World Bank 2007). The reliance on out-of-pocket health payments in financing health care exposes households to financial risk when health expenditures account for a large share of their income.

We want to shed a new light on this potentially negative effect when analyzing productivity gains that result from investment in health. The purpose of this paper is to study the impact of household health expenditures on agricultural productivity by examining the way in which these expenditures can both produce productivity gains and push people into poverty as a result of diminishing disposable income and disruption of material living standards of a household. This study provides a valuable contribution by assessing the linkage between the health sector and the agricultural sector using a computable general equilibrium (CGE) model for 2011 to 2020 and the most recent household survey data in Senegal (Poverty Monitoring Survey ESPS II). The contribution is empirical as well as methodological.

The rest of the paper is organized as follows. In Sect. 2, we provide some background knowledge by revisiting the linkage between health expenditures, health, and productivity. Section 3 then introduces the methodology used in this paper. Section 4.1 presents the simulation design developed in our research. Section 4.2 analyzes the distribution of catastrophic out-of-pocket health expenditures and their relationship with poverty. Finally, in Sect. 4.3, the linkage between health policies and agricultural productivity is analyzed through a CGE framework, which incorporates the issue of dynamic adjustments and spillover effects. Section 5 concludes.

Background

The health capital variable

A large body of literature has been developed on the macroeconomic and microeconomic relationship between health and productivity. Pitt and Rosenzweig (1986) developed a conceptual framework that evaluates the linkage between health and productivity and explains the mechanisms by which health affects utility and production. The authors defined utility as a function of the amount of produced food commodity, market-purchased food commodity, leisure, and health state. The latter is modeled through a production function linking changes in health inputs and health *status*. In their model, the agricultural commodity is produced according to a conventional production technology, with the additional consideration of the ability of the farmer's health *status* to affect the production level. Therefore, an increase in the farmer's health *status* will serve to produce more healthy time. This means that additional healthy days are available for leisure or for farm labor. Numerous studies have examined empirically the relationship between health variables and productivity at micro level. Using a stochastic agricultural production, Croppenstedt and Muller (2000) found that nutrition, distance to the source of water, and morbidity affect agricultural productivity in Ethiopia. Badiane and Ulimwengu (2009) also

Table 1 Simulation designs

Simulations' names	Simulations' description
$\boldsymbol{S}_1$ and $\boldsymbol{S'}_1$	Full ($\boldsymbol{S}_1$) and partial ($\boldsymbol{S'}_1$) coverage of the catastrophic out-of-pocket health payments financed by saving
$\boldsymbol{S}_2$ and $\boldsymbol{S'}_2$	Full ($\boldsymbol{S}_2$) and partial ($\boldsymbol{S'}_2$) coverage of the catastrophic out-of-pocket health payments financed by uniform direct tax rate for institutions, e.g., the percentage adjustment is the same for all institutions
$\boldsymbol{S}_3$ and $\boldsymbol{S'}_3$	Full ($\boldsymbol{S}_3$) and partial ($\boldsymbol{S'}_3$) coverage of the catastrophic out-of-pocket health payments financed by non-uniform direct tax rate
$\boldsymbol{S}_4$ and $\boldsymbol{S'}_4$	Full ($\boldsymbol{S}_4$) and partial ($\boldsymbol{S'}_4$) coverage of the catastrophic out-of-pocket health payments financed by uniform sales tax
$\boldsymbol{S}_5$ and $\boldsymbol{S'}_5$	Full ($\boldsymbol{S}_5$) and partial ($\boldsymbol{S'}_5$) coverage of the catastrophic out-of-pocket health payments financed by scaled sales tax
$\boldsymbol{S''}_1$	3 % annual decrease of tariffs on health goods, base value 2.5 %
$\boldsymbol{S''}_2$	3 % annual increases of activity subsidy to health sector, base value 10 %

Table 2 Distribution-sensitive catastrophic health expenditures (at national level)

Indices	Threshold budget share ξ_c				
	5 %	10 %	15 %	20 %	25 %
H_c	16.18 %	6.26 %	2.33 %	1.38 %	0.87 %
	(0.009)	(0.006)	(0.003)	(0.003)	(0.002)
Concentration index C^{H_c}	−0.051	−0.081	−0.087	−0.076	−0.27
	(0.019)	(0.031)	(0.047)	(0.066)	(0.077)
Ranked weighted H_c^w	17.01 %	6.77 %	2.53 %	1.48 %	1.10 %
$\bar{O}_i$	1.00 %	0.49 %	0.28 %	0.19 %	0.14 %
	(0.001)	(0.0008)	(0.0007)	(0.0006)	(0.0005)
Concentration Index $C^{\overline{O}_i}$	−0.152	−0.217	−0.285	−0.357	−0.411
	(0.044)	(0.068)	(0.088)	(0.104)	(0.117)
Ranked weighted $\overline{O}_i^w$	1.15 %	0.60 %	0.36 %	0.26 %	0.20 %

Source: Séne and Cissé 2015. Note: Standard errors in parentheses. Standard errors of the concentration indices are estimated using the Kakwani et al. (1997) estimator. The indexes are significant. The weighted measures also

used the stochastic frontier regression techniques and found a positive and significant relationship between health and agricultural technical efficiency in Uganda. Likewise, using cross-section data on hoe-cultivating farm households in Sierra Leone, Singh et al. (1986) established a link between nutritional status and labor productivity.

Health investment as an economic investment

Demand for health and health investment has led to a rich and controversial body of literature. Grossman (1972a, b) provided a theoretical framework consistent with the utility maximization to reflect the interdependence between health and expenditure patterns. Other authors also empirically explored the Grossman model (Zweifel and Breyer 1997; Cochrane et al. 1978; Stratmann 1999). Zweifel and Breyer (1997) found no evidence of a positive relationship between health and demand for medical care, whereas Grossman's model appears to predict a positive relationship. Cochrane et al. (1978) found that indicators of medical care usage are positively related to morbidity. However, these empirical studies might have an important limitation as they treated health as an exogenous variable. Stratmann (1999) showed that when controlling for endogeneity of health variables, medical services tend to decrease work loss days, in line with the predictions of the Grossman model.

In a recent study, Allen et al. (2014) examined the impact of health expenditures on agricultural labor productivity in order to inform the necessary policy decisions regarding the orientation of scarce public resources towards most effective uses in the context of Tanzania. They found that marginal productivity of labor as well as capital and fertilizers respond significantly to health expenditures. Fan and Zhang (2008) found that government's spending on agricultural research and extension improved agricultural productivity in Uganda, but no large impact was found for health. Benin et al. (2009) found that the provision of public goods and services in the agricultural, education, health, and rural road sectors had a substantial impact on agricultural productivity in Ghana.

A few applied studies analyzed the effects of health on non-health sectors, especially in agriculture using a general equilibrium framework. Savard and Adjovi (1997) developed a model in which health is incorporated in the form of improved labor productivity to take into account external effects. Some authors have developed models with a broad focus on the macroeconomic impact of diseases, for example, the HIV/AIDS[2] model that assesses the economic impact of HIV and AIDS (Kambou et al. 1992; Arndt 2003; Bell et al. 2003). Inclusion of the dynamic aspect is likely to improve understanding of the relation between health and economic outcomes, including income and labor productivity (McNamara et al. 2012).

It is widely recognized that health expenditures can boost productivity, but as stated earlier, these payments are a financial burden leading to impoverishment or limited efficiency when they become catastrophic, as households must reduce their expenditure on other necessities, and on agricultural inputs in the case of farmers. Our contribution is as follows. Unlike the previous studies, our analyses integrate the burden of catastrophic out-of-pocket health expenditures that might limit the extent of the impact of such expenditures on productivity after crossing a critical threshold. Another source of concern that we integrate is the dynamic and the spillover effects. Our approach also considers both the retroactive effects and the non-automatic adjustment of productivity with respect to health investment. Health spending will be linked to

[2] HIV (Human Immunodeficiency Virus); AIDS (Acquired Immune Deficiency Syndrome)

Table 3 Poverty and catastrophic out-of-pocket health expenditures

	CGE household groups								
	Rural agricultural poor	Rural agricultural rich	Rural non-agricultural poor	Rural non-agricultural rich	Urban agricultural poor	Urban agricultural rich	Urban non-agricultural poor	Urban non-agricultural rich	Senegal
H_c	4.37	5.07	6.32	8.24	10.30	3.59	4.72	7.16	6.26
H_c^g	5.91	5.64	7.72	9.19	5.46	3.93	9.82	7.57	7.82
		Rural agricultural	Rural non-agricultural		Urban agricultural	Urban non-agricultural		Senegal	
$P^0(pre)$		61.09	54.5		42.96	32.69		46.71	
$P^0(post)$		62.24	55.67		42.97	34.55		48.14	
ΔP^0		1.15	1.17		0.01	1.86		1.43	
$NP^1(pre)$		18.80	18.52		13.03	9.02		14.53	
$NP^1(post)$		19.55	19.62		13.8	9.65		15.35	
ΔNP^1		0.75	1.1		0.77	0.63		0.82	
$NP^2(pre)$		8.19	8.98		5.62	3.80		6.59	
$NP^2(post)$		8.64	9.99		6.06	4.09		7.16	
ΔNP^2		0.45	1.01		0.44	0.29		0.57	

Note: The above measures are for the 10 % threshold. NP^2 is the severity index. Source: The authors

the household production function to get the elasticity of productivity with respect to medical expenditures, which will be included in the CGE model. The estimated model accounts for the endogeneity of the health variables. We believe that our research is also relevant from a policy perspective as it provides policy recommendations regarding the protection against catastrophic expenditures and examines the interactions between the agriculture and health sectors.

The modeling framework

The theoretical framework presents the core CGE model and the microsimulations that we use to derive both the poverty measures and the catastrophic headcount ratios.

The CGE model

For our analysis, we use the model presented in Thurlow (2004) that is a dynamic extension of the standard model developed by the International Food Policy Research Institute (IFPRI) and documented in Lofgren et al. (2002). The model is calibrated using the 2011 agricultural Social Accounting Matrix (SAM).

Tables 6 and 7 in the Appendix provide a description of the model, and further explanation can be found in the above-mentioned papers which include the mathematical model statement with an equation-by-equation description, the features, and the data required. Recursive CGE computes static *equilibria* at each point in time, which are then linked in a long-run recursive path by specifying growth dynamics between time-steps (De Cian 2006). Based on this model, we incorporate interactions between health inputs purchased by households and agricultural productivity, while recognizing that the effects of the consumption of health goods on productivity might be lower when they constitute a large share of household income.

The CGE has 11 agricultural commodities as defined in the SAM. The aggregated agricultural sector includes livestock, forestry, and fisheries accounts. Detailed information about the non-agricultural sectors (industry and services) is also provided. The model aims to capture the linkage between all these various sectors. The model is written as a set of simultaneous equations, including several non-linear equations, defining the behavior of the different agents, as specified in the Appendix. The sectoral disaggregation of the accounts includes the following features: decomposition of the agricultural account into 11 crops *plus* livestock, fishing, and forestry and decomposition of the production into 14 regions. This allows for an efficient modeling of the agricultural sector in Senegal by taking into account as much as possible the sub-national heterogeneity in cropping patterns and resource

Table 4 Macroeconomic impacts

	Imports	Agricultural GDP	Private consumption
Simulations			
Initial	−2958.48	946.35	5733.16
BAU	3.70	3.54	3.33
S_1	3.52	3.68	3.55
S_2	3.45	3.73	3.63
S_3	3.45	3.71	3.63
S_4	3.52	3.72	3.62
S_5	3.53	3.70	3.63
S''_1	3.98	3.53	3.51
S''_2	3.68	3.59	3.36

endowments. Households are disaggregated into eight categories: rural and poor agricultural, rural and non-poor agricultural, rural and poor non-agricultural, rural and non-poor non-agricultural, urban and poor agricultural, urban and non-poor agricultural, urban and poor non-agricultural, and urban and non-poor non-agricultural households. The main feature that we include in our CGE model is the linkage between health expenditures and agricultural productivity that will be explained later.

The 2011 poverty monitoring survey (ESPS II) is used to model the demand side of the CGE. It covers 17,891 households with 5953 households constituting the sub-sample from which the questionnaire on expenditures was administrated. It is a random sample survey at national level and based on two-stage cluster sampling method. This survey aims to highlight the socio-economic characteristics of the different social groups (ANSD 2013).

Household consumption, including medical expenditures, is measured in local currency over the 12 months (or 30 days for food and some non-food consumption) preceding each household interview. The expenditure data is used to compute household income estimation. Health consumption expenditures include all food and non-food expenditures made by households to purchase goods and services in order to meet their health needs. The health sector is highlighted in the SAM, which uses the same structure of household health

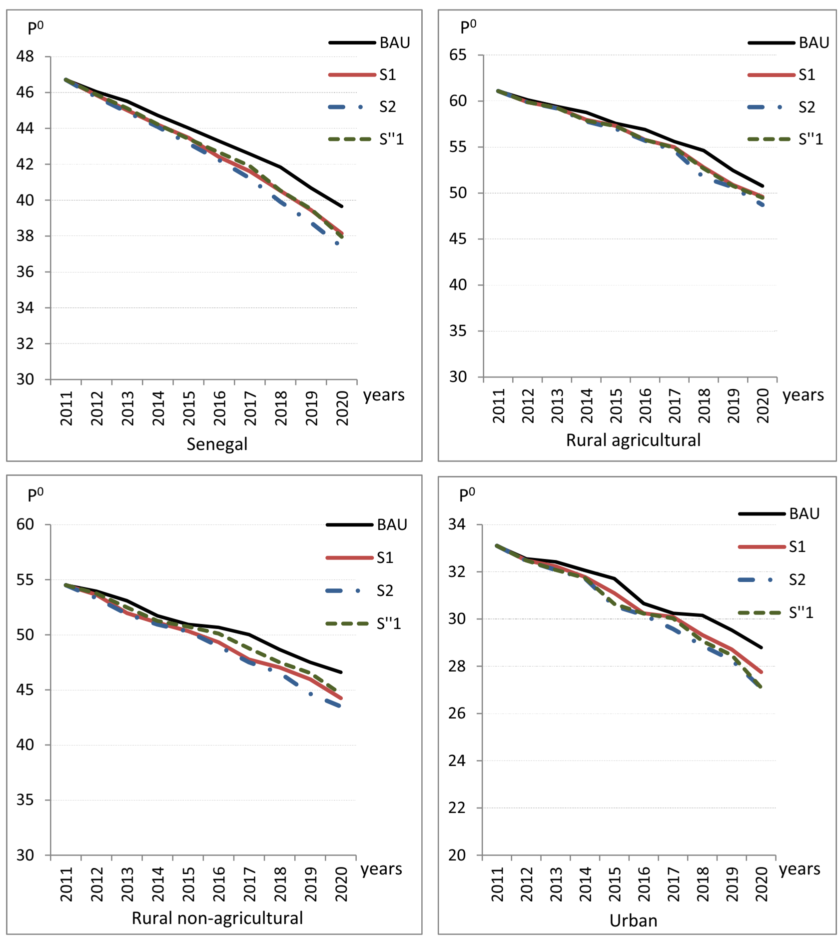


Fig. 1 Poverty evolution *per* household type for selected simulations

Source: The authors

Table 5 Poverty reduction and policy costs with respect to national poverty

Simulations	Poverty reduction $P_{0initial} - P_{02020}$	Estimated direct cost in year t	Estimated direct cost average over the simulation period (billion CFA)	Average government revenue loss, endogenous (billion CFA)
S_2	9.31	$\sum_{m=1}^{M^h} O_m \cdot Y_m = \sum_{m=1}^{M^h} T_m^h - \xi_c\, Y_m^h$	20.6	29.7
S'_2	9.47	$\sum_{m=1}^{M^h} \frac{1}{2} O_m \cdot Y_m = \sum_{m=1}^{M^h} \frac{1}{2}\left(T_m^h - \xi_c\, Y_m^h\right)$	10.3	76.5
S''_1	8.75	pwm(t) QM(t) EXR(t) tm0 $(1-(1-\tau)^n)$	0.018	44.1
S''_2	7.12	$-PA_{health}(t)QA_{health}(t)ta_{health}(1-(1+\rho)^n)$	1.66	10.0

Note: On May 23, 2014, 479.576 CFA Francs (African Financial Community) = US$1 (OANDA currency converter www.oanda.com). This is the currency used in West Africa

consumption as in the Poverty Monitoring Survey ESPS II, *plus* macro statistics from the National Agency for Demography and Statistics (ANSD). The SAM is balanced using the cross-entropy method as described in Robilliard and Robinson (1999).The model assumes that each producer a maximizes its profits by choosing the quantities, so that the marginal revenue products of the different factors are equal to their rents (Eq. 4). The structure of the production technology has at the top level a constant elasticity of substitution (CES) function of the quantities of value-added QVA and aggregate intermediate input $QINTA$. The former itself is a CES function of factors QF_f whereas the latter is a Leontief of disaggregated intermediate inputs $QINT$ as specified below (refer to Table 6 in the Appendix for the full list of notations).

$$QA_a = \alpha_a^a \cdot \left(\sum_{f \in F} \delta^a{}_a \cdot (QVA_{\ a})^{-\rho_a^{va}} + \left(1-\delta^a{}_a\right) \cdot (QINTA_{\ a})^{-\rho_a^{va}} \right)^{-\frac{1}{\rho_a^{va}}} \tag{1}$$

$$\frac{QVA_a}{QINTA_a} = \left(\frac{PINTA_a}{PVA_a} \cdot \frac{\delta_c^a}{1-\delta_c^a} \right)^{\frac{1}{\rho_a^a+1}} \tag{2}$$

$$QVA_a = \alpha_a^{va} \cdot \left(\sum_{f \in F} \delta_f^{va}{}_a \cdot (QF_{f\ a})^{-\rho_a^{va}} \right)^{-\frac{1}{\rho_a^{va}}} \tag{3}$$

$$W_f \cdot \overline{WFDIST}_{fa} = PVA_a \cdot (1-tva_a) \cdot QVA_a \cdot \left(\sum_{f \in F'} \delta_f^{va}{}_a \cdot (QF_{f\ a})^{-\rho_a^{va}} \right)^{-1} \cdot \delta_f^{va}{}_a \cdot (QF_{f\ a})^{-\rho_a^{va}-1} \tag{4}$$

$$QINT_{c\ a} = ica_{c\,a} \cdot QINTA_a \tag{5}$$

We assume that the growth rate of productivity depends on household health investment, which corresponds to the health goods purchased by households from the health sector. Health is considered as an investment good, meaning that its consumption is expected to provide productivity gains. Considering this, the total factor productivity α_a^{va} can be specified as endogenous and written as follows:

$$\alpha_a^{va}(t+1) = \alpha_a^{va}(t)\ (1 + \Phi(\Psi)) \tag{6}$$

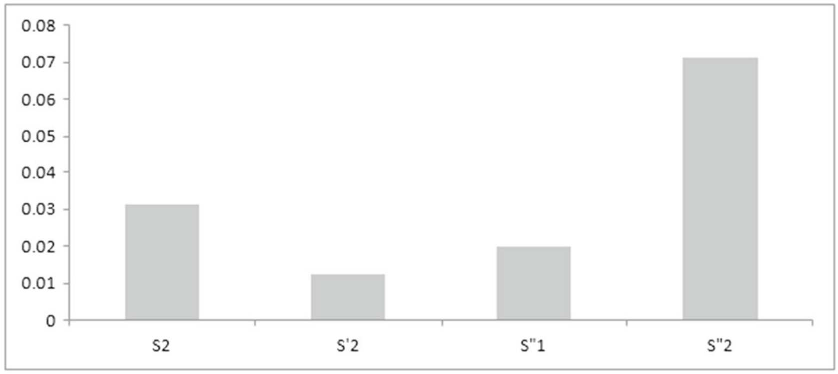
where Ψ is a health-related variable in relation to household health investment and Φ translates the incidence of our health-related variables on agricultural productivity.

We can write:

$$\alpha_a^{va}(t+1) = \alpha_a^{va}(t) \left(1 + \vartheta \sum_{h=1}^{G} \left(\frac{\Delta(P_{health}(h,t_0)Q_{health}(h,\ t-1))}{P_{health}(h,t_0)Q_{health}(h,\ t-1)} \right) \right) \tag{7}$$

with h the index for household groups within the model, G the number of household groups in the model, and $P_{health}(h,t_0)$ and $Q_{health}(h,t)$ respectively the price and the quantity of health goods consumed by household h at period t. The responsiveness of agricultural productivity to household consumption level of health inputs is captured through the elasticity parameter ϑ, which is estimated

Fig. 2 Poverty reduction ($P_{0initial} - P_{02020}$) *per* unit of government revenue loss for specific simulations



Source: The authors

using household level data. Each household maximizes a Stone-Geary utility function subject to a consumption expenditure constraint. The demand side of the health good consumption is as follows.

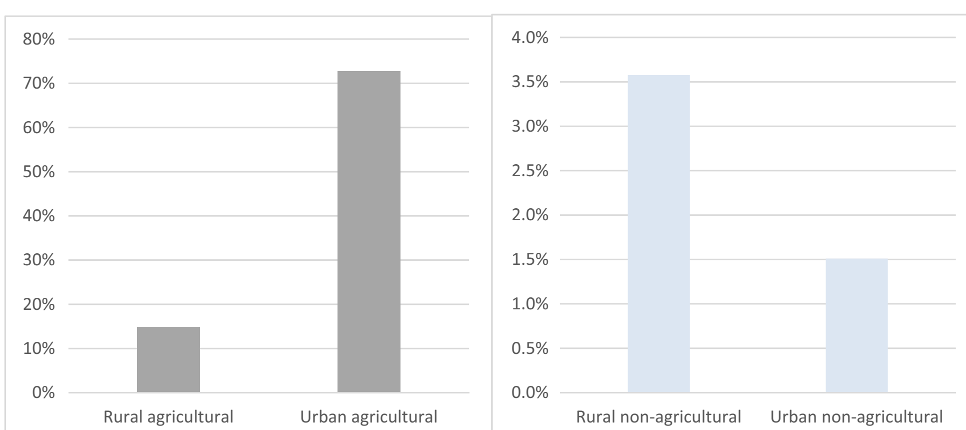
$$\mathrm{P_{health}}\ (\mathrm{h,t}).Q_h ealth(h,t) = \mu(h,t) + P_{(health)}(h,t).\gamma^m_{health}(h) + \beta^m_{Q_{health}}(h).\left(EH(h,t) - \sum\nolimits_{c' \in C} P_{c'} \cdot \gamma^m_{c'}(h)\right) \tag{8}$$

where $\gamma^m_{health}(h)$ represents the minimum consumption level of household h, $\beta^m_{health}(h)$ is the budget share of health goods in the household consumption basket, and $EH(h,t)$ is the actual consumption spending for household h. Besides, we include an exogenous shock $\mu(h,t)$ that represents the health environment and endowment (motivation of health center staffs, household's health endowment, geographic accessibility of health centers, etc.). It is calibrated using the distribution of residuals derived from health expenditure equation estimated by using the survey data (see Sect. 4.3 and the note below Table 8 for the distribution). Changing the magnitude of this environmental factor could allow for an exogenous increase of households' health expenses up to the threshold level or a reduction below. This might be interesting in the case where one would like to simulate policies that exogenously compel households to more or less direct their expenditures towards health goods and services, or in the case where unexpected shock-related expenditures are simulated. However, our policy simulation setup does not concentrate on these questions. Here, health care demand behavior is determined mainly by the postulate of utility maximization, as widely accepted in the literature. In fact, it is more realistic to let the households decide on how much to spend on the different available goods based on available income, well-being, and the general equilibrium price substitution effects.

The microsimulation module

To assess the impact on poverty, we use a microsimulation model which takes into account the poverty distribution in the country. Just as the CGE model, the poverty microsimulation module is also calibrated to the 2011

Fig. 3 Relative variation of poverty *per* billion transferred (average over the simulation period) for specific household groups



Source: The authors

Senegalese household poverty monitoring survey—ESPS II. Endogenous changes in consumption resulting from the CGE model are passed down to the household by linking each of the household in the microsimulation model to the corresponding household in the CGE. The method is a non-parametric microsimulation where the calculated poverty indexes are the Foster-Greer-Thorbecke (FGT) family of poverty measures that propose summary indicators of the extent of poverty:

$$FGT = \frac{1}{M} \cdot \sum_{(m=1)}^{M} \left(\frac{z - y_m}{z}\right)^{\partial} . I(y_m \leq z) \tag{9}$$

where z is the poverty line, M is the number of households in the survey, y_m is the income of household m, and $I(y_m \leq z)$ is an indicator function which is equal to 1 when $y_m \leq z$ and zero otherwise. For $\alpha = 0$, the FGT index collapses to the headcount *ratio* P_0, which is the most widely used poverty measure that quantifies the proportion of the population that is poor, but does not show how poor the poors are. The case where $\alpha = 1$ gives the poverty gap index (P_1) that measures the extent to which individuals fall below the poverty line as a proportion of the poverty line. The sum of these poverty gaps gives the *minimum* cost of eliminating poverty with a perfect targeting of transfers. The case where $\alpha = 2$ gives an indication on the severity by squaring the normalized gap (P_2) and thus weights the gap by the gap.

The cost of basic need method approach is used to define the poverty line. This method first estimates the cost of acquiring enough food for adequate nutrition, namely, 2400 calories *per* adult *per* day, and then adds the cost of other essentials. We also define a new poverty measure to integrate the impoverishment effect corresponding to the extent to which households are pushed into poverty by making out-of-pocket health expenditures.

The last part of the section describing the CGE model shows the linkage between productivity and health expenditures. However, given the fact that we want to capture more accurately the effect of household health payments, we allow this relation (Eq. 7) to depend also on the magnitude of catastrophic out-of-pocket health payments through the inclusion of the household group's related headcount *ratio* that we define as follows:

$$H_c^h = \frac{1}{M^h} \sum_{m=1}^{M^h} Ind\left(\frac{T_m^h}{Y_m^h} - \xi_c\right) \tag{10}$$

where *Ind* (.) equals 1 if $\frac{T_m^h}{Y_m^h} > \xi_c$ and 0 otherwise, ξ_c represents the threshold above which the *ratio* of health expenditures to income ($\frac{T_m^h}{Y_m^h}$) is considered as catastrophic, M^h the sample size of the aggregated household group h, and Y_m^h is the income, with m subscript for household within the aggregate group h.

Out-of-pocket payments are considered catastrophic and poverty increasing if they exceed 40 % of annual non-food expenditures by households (Kawabata et al. 2002; Xu et al. 2003; Karami et al. 2009) or 10 % of the *ratio* between health expenditures and consumption expenditures (Pradhan and Prescott 2002; Wagstaff and Van Doorslaer 2003; Russell 2004). In our case, catastrophic payments are defined with regard to the total household expenditures.

$\boldsymbol{H}_c^h$ gives an estimate of the proportion of households who experienced health payments above the threshold ξ_c within each household group in the SAM. It is endogenous and calculated each year after transmitting changes in health expenditures and income from household groups in the CGE model to the corresponding households in the microsimulation module, similar to the calculation of poverty measures.

$\boldsymbol{H}_c^h$ is related to the severity of morbidity level within the different household groups and translates the effectiveness of health inputs in generating technical progress. If all households within a given household group h spend on health goods without catastrophic outcomes as defined here, then there is a perfect transmission of investment in health inputs to productivity in line with the elasticity ϑ.

Considering this, Eq. (7) can be rewritten in the following manner:

$$\alpha_a^{va}(t+1) = \alpha_a^{va}(t)\left(1 + \vartheta \sum_{h=1}^{G} \frac{\Delta(P_{health}(h, t_0)Q_{health}(h, t))}{P_{health}(h, t_0)Q_{health}(h, t-1)} \left(\boldsymbol{H}_c^h(t)\right)^{\left(1-1_{[\Delta(PQ)>0]}\right)} \left(1-\boldsymbol{H}_c^h(t)\right)^{1_{[\Delta(PQ)>0]}}\right) \tag{11}$$

The model is intended to take into account the potential non-automatic adjustment of productivity with respect to health investments. Moreover, the general *equilibrium* framework allows integrating the bi-directional linkage between productivity and health expenditures. Health expenditures enhance productivity, which ultimately increases household income and therefore the capacity to invest in goods and services that can maintain or potentially improve health and provide energy for the farmers.

The logic behind Eq. (11) is that if health expenditures increase (i.e., $\Delta PQ > 0$) for a household group in the model compared to the previous periods, the positive impact on productivity depends not only on the estimated parameter ϑ but also on the share of households who had not incurred catastrophic health expenditures $(1-\boldsymbol{H}_c^h(t))$. This amount is provided by the health module of the household survey and updated with the microsimulation module. Therefore, a lower $\boldsymbol{H}_c^h(t)$ tends to generate more technical progress. Similarly, if $\Delta PQ<0$, the extent through which productivity is reduced depends this time on the share of households that faces catastrophic expenditures. If $\Delta PQ=0$ for all individuals, then productivity remains at the same level. Indicator functions are used for a mathematical and straightforward formulation.

Catastrophic out-of-pocket health payments might reduce the full impact of health investment on productivity while at the same time negatively affect the capacity of farm laborers to afford food and nutrients that they need for the maintenance of good health and energy. The high share of out-of-pocket household payments can also lead to negative effects on the efficient use of fertilizer and other traditional agricultural inputs, in a context where household purchasing power decreases as a result of lower disposable incomes. Households who incur catastrophic expenditures can be forced to cut down on subsistence needs and sell productive goods in response to the financial shock. In addition, catastrophic out-of-pocket health payments might reflect very severe shock on the household health *status*. These issues are incorporated in the model following the specification in Eq. (11) that stipulates that aggregated household groups with fewer occurrences of catastrophic payments are more likely to achieve their *maximum* potential productivity gains resulting from the consumption of health goods.

The proposed framework integrates the externality effects between sectors and therefore determines the economy-wide impacts of the structure and the changes in household out-of-pocket health payments. One strength of our paper is that shift in productivity is endogenized and no technological progress is assumed ad hoc, as it is commonly done in the CGE literature.

Policy simulations and discussion

Simulation designs

When designing policies that integrate health into agriculture, it is essential to consider some negative effects that might exist when household out-of-pocket expenditures exceed a critical threshold in terms of share of total income. As explained earlier, our study attempts to provide evidence on this issue. It shows the advantage of providing financial protection by examining the long-run effects of policies that mitigate the consequences of catastrophic health payments on individuals. The simulations are run over a 10-year period from 2011 to 2020.

Under the first policy that is simulated, the government would pay for the cost of drugs beyond amounts that might otherwise threaten the financial security of a given household. In this case, we also simulate alternative options for the government to pay for the policy and the resulting impact on the economy and household well-being. In the first option, the excess or catastrophic share of expenditures is entirely supported by the government and financed through reduced public savings or through increased taxes on domestic institutions or on commodities, whether uniformly or not.

This is simulated by transferring amounts equivalent to full payment overshoot $\sum_{m=1}^{M^h} O_m.\, Y_m = \sum_{m=1}^{M^h} T_m^h - \xi_c\, Y_m^h$ to each household group in each period in order to eliminate the impoverishing effects of out-of-pocket health expenditures. The size of the catastrophic payment overshoot captures the intensity of the occurrence of catastrophic expenditures. In order to reduce the fiscal burden of the policy and ensure its sustainability, an option with transfers equivalent to 50 % of catastrophic out-of-pocket health payments is also presented in the Appendix. In this cost-sharing option, households bear half of the cost up to the critical threshold.

Adoption of mutual health insurance can also be a more efficient funding mechanism regarding sustainability. Insurance coverage is practically absent among workers in the informal sector and very low in the formal sector[3]; only 20 % of the population is covered by health insurance (Pereznieto 2009).

The second policy option is to reduce the price of health good for households. This price reduction could come from productivity gains in the domestic health producing sector, government subsidies, or reduction of the import tariffs on imported health goods. We consider only the last two channels. Most of the drugs used in Senegal (85–90 %) are imported with relatively high margins, which contributes to their relative inaccessibility (Ministry of Health and Prevention 2009). Drugs imported from outside the WAEMU and ECOWAS[4] are subject to a tax rate of 2.5 %. We simulate the impact of an annual 3 % decrease in the duty rate τ over the simulation period. This duty escalator, meaning a progressive liberalization, is likely to mitigate the burden of health good expenditures and give incentive to households to invest more in health. Under this scenario, the associated direct cost *per* year is given by the lost revenue resulting from the lowering import tariffs for health goods that is $pwm\ QM\ EXR\ tm0\ (1-(1-\tau)^n)$, where *pwm* is the import price, *QM* the quantity of imported health good, *tm*0 the initial

[3] A *sesame plan* (free care for the elderly) was introduced in 2006, but as many other initiatives offering financial protection methods and health services, such programs are jeopardized by political instability.

[4] WAEMU: West African Economic and Monetary Union
ECOWAS: Economic Community of West African States

import tariff, n the number of years between the base year 2011 and the current simulation period t in the dynamic model, and EXR the exchange rate. We also simulate an alternative option of a 3 % annual increase of subsidy ρ to the domestic health sector. The size of the simulations is not critical here, as simulating different levels might generate the same types of mechanisms in the economy. The different *scenarii* are ranked using as criterion the degree of poverty reduction achieved *per* unit of lost government revenue. Table 1 describes the different policy simulations.

The distribution of catastrophic out-of-pocket health expenditures

Before discussing the simulation results, we want to highlight the magnitude and the distribution of out-of-pocket health expenditures across household groups. We also discuss the extent to which these expenditures are likely to have poverty-exacerbating effects and productivity-lowering effects among households.

We use the mean positive gap to assess the magnitude of the catastrophic impact of household out-of-pocket health expenditures, that is, to see how excessive they are. In contrast to the headcount *ratio*, it gives an indication of how much consumer payments exceed the threshold amount. At the national level, it is computed using the following formula:

$$H_c^g = \bar{\boldsymbol{O}}_i \Big/ H_c = \sum_m^M \left(\frac{T_m}{Y_m} - \xi_c\right) Ind\left(\frac{T_m}{Y_m} - \xi_c\right) \Big/ \sum_{m=1}^M Ind\left(\frac{T_m}{Y_m} - \xi_c\right) \tag{12}$$

where $\bar{\boldsymbol{O}}_i$ represents the average of overshoot payment $O_m = \frac{T_m}{Y_m} - \xi_c$. The expression measures the intensity of the occurrence of catastrophic out-of-pocket expenditures.

To measure the inequality in health expenditures, concentration indices[5] $\boldsymbol{C}^{\boldsymbol{H}_c}$ and $\boldsymbol{C}^{\bar{\boldsymbol{O}}_i}$ are used to compute weighted headcount $\boldsymbol{H}_{\boldsymbol{c}}^{\boldsymbol{w}} = H_c\left(1-\boldsymbol{C}^{\boldsymbol{H}_c}\right)$ and weighted overshoot $\bar{\boldsymbol{O}}_i^w = \bar{\boldsymbol{O}}_i\left(1-\boldsymbol{C}^{\bar{\boldsymbol{O}}_i}\right)$. This allows us to see whether the households who experienced catastrophic health expenditures were unequally distributed across the population, between the richest and the poorest households.

The calculations of the indices help illustrate the impact of household out-of-pocket health expenditures on poverty when they reach catastrophic levels. These measures elucidate the impoverishment effect which corresponds to the extent to which households are pushed into poverty and likely to become unable to achieve their maximum level of potential productivity due to catastrophic out-of-pocket health expenditures.

Let Z_{pov} (pre) be the pre-payment poverty line and x_m the pre-payment income *per* adult equivalent of household m. We use the FGT class of poverty indices that can be defined as follows.

The pre-payment poverty headcount is:

$$P^0(pre) = \frac{1}{H}\sum_{m=1}^{M} Ind\left(x_m - Z_{pov}(pre)\right) \tag{13}$$

The pre-payment poverty gap is:

$$P^1(pre) = \frac{1}{H}\sum_{m=1}^{M} \left(\left(x_m - Z_{pov}(pre)\right)\right) \tag{14}$$

The normalized pre-payment poverty gap controls for differences in poverty lines between strata and is expressed as:

$$NP^1(pre) = \frac{P^1(pre)}{Z_{pov}(\mathrm{pre})} \tag{15}$$

We compare the pre- and post-payment measures, in order to measure the poverty effects of out-of-pocket health payments, as follows:

$$\varDelta P^0 = P^0(post) - P^0(pre) \tag{16}$$

$$\varDelta P^1 = P^1(post) - P^1(pre) \tag{17}$$

$$\varDelta NP^1 = NP^1(post) - NP^1(pre) \tag{18}$$

In the post-payment measures, the income *per* adult equivalent x_i is recomputed by subtracting household out-of-pocket health payments, and the poverty line Z_{pov} (pre) is adjusted by deducting an amount of the poverty line derived from health spending among the group that provides the reference for the non-food-based poverty line. The results are discussed further below (and will be presented in Table 3).

Although the CGE simulations are based on a threshold value of 10 %, Table 2 considers a range of threshold values and illustrates the extent to which catastrophic payments can push people into poverty.[6] The higher thresholds (20 and 25 %) represent an extremely severe definition of the catastrophe owing to higher out-of-pocket costs. In general, the results in Table 2 show negative concentration indices and higher values for the weighted gap from critical thresholds and the weighted headcount compared to the unweighted measures. This indicates a greater tendency for the poor to incur financial catastrophe.

[5] $C = \frac{2}{M\mu}\sum_{m=1}^{M} h_m r_m - 1 - \frac{1}{M}$ where h_m is the health variable, μ its mean, and r_m the fractional rank of household m in the living standards distribution where income *per* adult equivalent is the measure of living standards. For more details, see Kakwani et al. 1997; O'Donnell et al. 2008.

[6] The 10 % threshold is the most common—albeit arbitrary—threshold in the literature (Pradhan and Prescott 2002; Wagstaff and Van Doorslaer 2003; and Russell 2004). The rationale is that this represents an approximate threshold at which the household is forced to sacrifice other basic needs, sell productive assets, incur debt, or become impoverished (Russell 2004).

At the 10 % threshold, the prevalence of catastrophic out-of-pocket health expenditures is estimated at 6.26 %. The size of the excess of catastrophic out-of-pocket health spending stands at 7.82 % of the household income at the national level, as shown by the mean of positive gap in the last column of Table 3.

Results show that catastrophic out-of-pocket health payments exacerbate poverty. Estimations reveal that the conventional poverty headcount *ratio* for Senegal increases by 1.43 percentage points when controlling for catastrophic out-of-pocket health expenditure ($\Delta \boldsymbol{P}^0$). The average deficit to reach the poverty line also increases due to the burden of excessive health payments ($\Delta \boldsymbol{P}^1$). When extrapolating at national level, we found that a large number of people (195, 716)[7] that encountered catastrophic health expenditures were pushed into poverty due to the burden of excessive health expenditures (for more details on the out-of-pocket health expenditures, see Séne and Cissé 2015). The headcount *ratio* $\boldsymbol{H_c}$ varies across household groups, reaching a *maximum* value for urban agricultural household group (10.30 %). Therefore, the impact of out-of-pocket health expenditures on productivity might be heterogeneous across the aggregated household groups within the CGE model.

CGE simulation results and the macroeconomic implications

All the simulations are based on the endogenous technical progress growth that is generated by the consumption of health goods and take into account the effect of catastrophic out-of-pocket health expenditures in the transmission mechanisms.

The elasticity of productivity with respect to health goods consumption, ϑ, is presented in Table 8 in the Appendix. It is estimated through a two-stage least square (2SLS) and a multilevel mixed-effects linear (MMEL) regression, allowing random intercept combined with a two-stage residual inclusion (2SRI)[8] to correct for endogeneity. Both estimations provide approximately the same value for ϑ. The instruments of medical spending are good predictors, and the Kleibergen-Paap rank Wald F-statistic[9] as well as the Hansen J test reveal the appropriateness of the instruments.

Table 4 shows the macroeconomic impacts of the different simulations. In the base-run simulation, we assume that the gross domestic product (GDP) grows at around a quite realistic rate of 3.7 % for the period considered here (2011–2020), which is the observed average growth rate for the period 2005–2011. The agricultural GDP has been characterized by erratic growth levels during this period, reaching the highest point of 18.5 % in 2008 and the lowest (−13.1 %) in 2011. The baseline *scenario* (Business As Usual, BAU) assumes that the annual agricultural GDP growth rate for 2011–2020 is 3.5 %, which reflects the recent performance in the overall agricultural sector. The baseline also assumes the continuation of demographic trends. Urban population is supposed to grow at 2.5 %, while rural population grow at 2.1 %. The annual growth rate of government consumption is fixed at 3.9, as well as the growth rate of foreign savings, to reflect the past trend in these key variables. Economic growth also results from increases in factors. We assume a homogenous land expansion within the different agricultural crop production systems of 1.9 %. Capital accumulation grows endogenously as a result of the dynamic interaction between investment and saving across the periods. The various results show an increase in agricultural GDP compared to the baseline *scenario* as a response to productivity gains in the agricultural sector resulting from alternative policy options to reduce the burden of catastrophic out-of-pocket health expenditures. Under *scenarii* S_1 (tariff reduction) and S_2 (increase in subsidy), the decrease in the price of health goods consumed by households raises total private consumption in the economy. The quantity of imported goods increases following the tariff reduction in S_1. Simulations of the full coverage of the catastrophic out-of-pocket health payments (S_s simulations, $s=1,\ldots,5$) have the same direct cost that equals the overall transfer payments households receive from the government. These simulations show that the agricultural growth does not change much in general with the funding options. However, we can observe slightly more impact when the funding option relies on uniform direct tax rate for institutions (S_2) with 3.73 % average growth rate over the simulation period.

Figure 1 and Table 9 in the Appendix summarize the key results in terms of poverty reduction. The poverty evolutions in Fig. 1 are drawn only for the selected simulations BAU, S_1, S_2, and S_1 for a good visualization.[10] For the remaining simulations, the detailed results are presented at national level in the Appendix.

Scenario S_2 shows the large impact on poverty reduction at national level (2.26 percentage points) among the full expenditure coverage *scenarii*. In this *scenario*, the government takes the burden off households by removing

[7] Namely, the increase in the poverty headcount *ratio* (1.43 %) times population size estimated at 13,591,436 millions (ANSD, 2013)

[8] For more details, see Garen 1984; Vella 1993; Terza et al. 2008; Wooldridge 2010.

[9] See Stock and Yogo 2005; Baum et al. 2003; Kleibergen and Paap 2006.

[10] In fact, some simulations might overlap because they present a very similar poverty path, albeit with marginal differences. Figure 1 only shows evidence that policy options concerning catastrophic health payments have a potential for poverty reduction and does not intend to compare simulations of different types.

the financial shock of out-of-pocket health expenditures, using uniform direct tax rate for institutions as a funding option. This illustrates the potentially significant implications of catastrophic health expenditures on households' welfare.

The *scenarii* lowering import tariffs and increasing subsidies to the health sector also have poverty-reducing effects, albeit marginal for the subsidy *scenario*. Regarding this direction, larger shocks would affect more prices and would have greater impacts. All simulations have the effect of increasing the consumption of health goods compared to the baseline, especially for the subsidy simulation, as indicated in Table 10 in the Appendix. In general, the growth rate of health group consumption is higher for urban non-agricultural and rich households with 4 % for S_2 and around 3.7 % for S_1.

On average, rural areas experience a larger reduction in poverty than urban areas in almost all the simulations. For example, the poverty rate in the whole rural area decreases by 2.69 percentage points in S_2 compared to the counterfactual *scenario*, while there is a reduction of 1.7 percentage points in urban areas.

The comparison of full coverage simulations with the partial coverage simulation and the tariff and subsidy simulations requires taking into account the endogenous government revenue losses beyond the estimated direct cost in Table 5. Therefore, we calculate the response of poverty reduction in unit of government revenue loss (ξ) for simulations S_2 and S_2 (that show, respectively, larger impacts among the full coverage and partial coverage simulations), for import tariff and subsidy simulations. These effects are expressed as absolute poverty reduction *per* unit of average government revenue loss over the simulation period for each *scenario*.

As shown in Fig. 2, subsidizing the health sector (S_2) and full coverage of catastrophic out-of-pocket health expenditures financed by a uniform tax on institutions (S_2) are found to yield greater efficiency gains in the long run, than the other simulations.

In addition, we analyze the public transfers' effectiveness of the full coverage *scenario* (financed by uniform direct taxes) between household groups *h* by scaling their relative poverty change $(P_{0initial}{}^{h} - P_{02020}{}^{h}) / P_{0initial}{}^{h})$ to the specific amount of money they received. Figure 3 shows the variation of the poverty reduction *per* unit of money received, for each household group. Our results indicate higher effectiveness for agricultural households, especially those in urban areas who are the most frequently affected by catastrophic health payments.

Conclusion

This paper has outlined the issue of integrating the relationship between health expenditures and productivity in a dynamic CGE model. It also focused on the impact of catastrophic out-of-pocket health payments on the economy, taking the specific case of Senegal during 2011–2020. According to the analysis of out-of-pocket health payments, there is evidence that many households are pushed into poverty by unforeseeable catastrophic expenditures. The idea that health good consumption has a positive impact on productivity is widely recognized in the existing literature, especially in microeconomics. This paper simulates the macroeconomic impact of alternative government policies to protect households from the effects of catastrophic payment overshoot.

It also examines the ways in which policies affect health good prices, their consumption, productivity, and ultimately the level of poverty. The model is a recursive dynamic CGE with the agricultural technical progress modeled as endogenous and depending on the change of health consumption over time. Results reveal that policies reducing the cost and promoting consumption of health goods have a significant and positive impact on the agricultural sector growth and important spillover effects on the rest of the economy. The simulations also show considerable productivity gains and poverty-reducing effects resulting from policies protecting vulnerable households against large unpredictable financial costs of illness.

The various *scenarii* show that programs protecting against catastrophic out-of-pocket health expenses are workable options to reduce the long-term impoverishing effects on vulnerable households. The potential returns in terms of reducing poverty and enhancing long-term economic growth far outweigh related potential fiscal costs. The results highlight the need to have an efficient health care system that does not put the entire financial burden of health services on households, in particular in the case of major illnesses. The gains in terms of long-term growth and progress in poverty reduction can be substantial. Subsidizing the provision of health goods and providing full coverage of catastrophic out-of-pocket health expenditures through uniform taxes on institutions can be cost-effective policy options. The main target of such policies should be poor and more vulnerable groups, such as rural and urban agricultural households, who are the most affected by catastrophic out-of-pocket health expenditures.

Appendix

Table 6 Model sets, parameters, and variables

Symbol	Explanation	Symbol	Explanation
Sets			
$a \in A$	Activities	$c \in CMR(\subset C)$	Regionally imported commodities
$a \in ALEO(\subset A)$	Activities with a Leontief function at the top of the technology nest	$c \in CMNR(\subset C)$	Non-regionally imported commodities
$c \in C$	Commodities	$c \in CT(\subset C)$	Transaction service commodities
$c \in CD(\subset C)$	Commodities with domestic sales of domestic output	$c \in CX(\subset C)$	Commodities with domestic production
$c \in CDN(\subset C)$	Commodities not in *CD*	$f \in F$	Factors
$c \in CE(\subset C)$	Exported commodities	$i \in INS$	Institutions (domestic and rest of world)
$c \in CEN(\subset C)$	Commodities not in *CE*	$i \in INSD(\subset INS)$	Domestic institutions
$c \in CM(\subset C)$	Aggregate imported commodities	$i \in INSDNG(\subset INSD)$	Domestic non-government institutions
$c \in CMN(\subset C)$	Commodities not in *CM*	$h \in H(\subset INSDNG)$	Households
Parameters			
$cwts_c$	Weight of commodity *c* in the CPI	pwm_c	Import price (foreign currency)
$dwts_c$	Weight of commodity *c* in the producer price index	$pwmr_{cr}$	Import price by region (foreign currency)
ica_{ca}	Quantity of *c* as intermediate input *per* unit of activity *a*	$qdst_c$	Quantity of stock change
$icd_{cc'}$	Quantity of commodity *c* as trade input *per* unit of *c*′ produced and sold domestically	$\overline{qg}_c$	Base-year quantity of government demand
$ice_{cc'}$	Quantity of commodity *c* as trade input *per* exported unit of *c*′	$\overline{qinv}_c$	Base-year quantity of private investment demand
$icer_{cc'r}$	Quantity of commodity *c* as trade input *per* exported unit of *c*′ from region *r*	$shif_{if}$	Share for domestic institution *i* in income of factor *f*
$icm_{cc'}$	Quantity of commodity *c* as trade input *per* imported unit of *c*′	$shii_{ii'}$	Share of net income of *i*′ to *i* (*i*′ ∈ INSDNG’; *i* ∈ INSDNG)
$icmr_{cc'r}$	Quantity of commodity *c* as trade input *per* imported unit of *c*′ from region *r*	ta_a	Tax rate for activity *a*
$inta_a$	Quantity of aggregate intermediate input *per* activity unit	$\overline{tins}_i$	Exogenous direct tax rate for domestic institution *i*
iva_a	Quantity of aggregate intermediate input *per* activity unit	$tins01_i$	0–1 parameter with 1 for institutions with potentially flexed direct tax rates
$\overline{mps}_i$	Base savings rate for domestic institution *i*	im_c	Import tariff rate
$mps01_i$	0–1 parameter with 1 for institutions with potentially flexed direct tax rates	tmr_{cr}	Regional import tariff
pwe_c	Export price (foreign currency)	tq_c	Rate of sales tax
$pwer_{cr}$	Export price by region (foreign currency)	$trnsfr_{if}$	Transfer from factor *f* to institution *i*
Greek symbols			

Table 6 (continued)

Symbol	Explanation	Symbol	Explanation
α_a^a	Efficiency parameter in the CES activity function	δ_c^t	CET function share parameter
α_a^{va}	Efficiency parameter in the CES value-added function	δ_{fa}^{va}	CES value-added function share parameter for factor *f* in activity *a*
α_c^{ac}	Shift parameter for domestic commodity aggregation function	γ_{ch}^m	Subsistence consumption of marketed commodity *c* for household *h*
α_c^q	Armington function shift parameter	θ_{ac}	Yield of output c *per* unit of activity *a*
α_c^t	CET function shift parameter	ρ_a^a	CES production function exponent
α_c^m	Shift parameter in the CES regional import function	ρ_a^{va}	CES value-added function exponent
α_c^e	Shift parameter in the CES regional export function	ρ_c^{ac}	Domestic commodity aggregation function exponent
β^a	Capital sectoral mobility factor	ρ_c^q	Armington function exponent
β_{ch}^m	Marginal share of consumption spending on marketed commodity *c* for household *h*	ρ_c^t	CET function exponent
δ_a^a	CES activity function share parameter	ρ_c^m	Regional imports aggregation function exponent
δ_{ac}^{ac}	Share parameter for domestic commodity aggregation function	ρ_c^e	Regional exports aggregation function exponent
δ_c^q	Armington function share parameter	η_{fat}^a	Sector share of new capital
υ_f	Capital depreciation rate		
Exogenous variables			
$\overline{CPI}$	Consumer price index	$\overline{MPSADJ}$	Savings rate scaling factor (=0 for base)
$\overline{DTINS}$	Change in domestic institution tax share (=0 for base; exogenous variable)	$\overline{QFS}_f$	Quantity supplied of factor
$\overline{FSAV}$	Foreign savings (FCU)	$\overline{TINSADJ}$	Direct tax scaling factor (=0 for base; exogenous variable)
$\overline{GADJ}$	Government consumption adjustment factor	$W\bar{FDIST}_{fa}$	Wage distortion factor for factor *f* in activity *a*
$\overline{IADJ}$	Investment adjustment factor		
Endogenous variables			
AWF_{ft}^a	Average capital rental rate in time period *t*	QF_{fa}	Quantity demanded of factor *f* from activity *a*
$DMPS$	Change in domestic institution savings rates (=0 for base; exogenous variable)	QG_c	Government consumption demand for commodity
DPI	Producer price index for domestically marketed output	QH_{ch}	Quantity consumed of commodity *c* by household *h*
EG	Government expenditures	QHA_{ach}	Quantity of household home consumption of commodity *c* from activity *a* for household *h*
EH_h	Consumption spending for household	$QINTA_a$	Quantity of aggregate intermediate input
EXR	Exchange rate (LCU per unit of FCU)	$QINT_{ca}$	Quantity of commodity *c* as intermediate input to activity *a*
$GOVSHR$	Government consumption share in nominal absorption	$QINV_c$	Quantity of investment demand for commodity
$GSAV$	Government savings	QM_c	Quantity of imports of commodity *c*
$INVSHR$	Investment share in nominal absorption	QMR_{cr}	Quantity of imports of commodity *c* by region *r*
MPS_i	Marginal propensity to save for domestic non-government institution (exogenous variable)	QER_{cr}	Quantity of exports of commodity *c* to region *r*
PA_a	Activity price (unit gross revenue)	QQ_c	Quantity of goods supplied to domestic market (composite supply)
PDD_c	Demand price for commodity produced and sold domestically	QT_c	Quantity of commodity demanded as trade input

Table 6 (continued)

Symbol	Explanation	Symbol	Explanation
PDS_c	Supply price for commodity produced and sold domestically	QVA_a	Quantity of (aggregate) value-added
PE_c	Export price (domestic currency)	QX_c	Aggregated quantity of domestic output of commodity
PER_{cr}	Export price by region (domestic currency)	$QXAC_{ac}$	Quantity of output of commodity *c* from activity *a*
$PINTA_a$	Aggregate intermediate input price for activity *a*	RWF_f	Real average factor price
PK_{ft}	Unit price of capital in time period *t*	$TABS$	Total nominal absorption
PM_c	Import price (domestic currency)	$TINS_i$	Direct tax rate for institution *i* ($i \in$ INSDNG)
PMR_{cr}	Import price by region (domestic currency)	$TRII_{ii'}$	Transfers from institution *i'* to *i* (both in the set INSDNG)
PQ_c	Composite commodity price	WF_f	Average price of factor
PVA_a	Value-added price (factor income per unit of activity)	YF_f	Income of factor *f*
PX_c	Aggregate producer price for commodity	YG	Government revenue
$PXAC_{ac}$	Producer price of commodity *c* for activity *a*	YI_i	Income of domestic non-government institution
QA_a	Quantity (level) of activity	YIF_{if}	Income to domestic institution *i* from factor *f*
QD_c	Quantity sold domestically of domestic output	ΔK^a_{fat}	Quantity of new capital by activity *a* for time period *t*
QE_c	Quantity of exports		

Source: Adapted from Lofgren et al. (2002) and Thurlow (2004)

Table 7 Model equations

Production and price equations

$$QINT_{c\,a} = ica_{c\,a} \cdot QINTA_a \tag{A1}$$

$$PINTA_a = \sum_{c \in C} PQ_c \cdot ica_{ca} \tag{A2}$$

$$QVA_a = \alpha_a^{va} \cdot \left(\sum_{f \in F} \delta_{f\,a}^{va} \cdot \left(\alpha_{f\,a}^{vaf} \cdot QF_{f\,a} \right)^{-\rho_a^{va}} \right)^{-\frac{1}{\rho_a^{va}}} \tag{A3}$$

$$W_f \cdot \overline{WFDIST}_{fa} = PVA_a \cdot (1 - tva_a) \cdot QVA_a \cdot \left(\sum_{f \in F'} \delta_{f\,a}^{va} \cdot \left(\alpha_{f\,a}^{vaf} \cdot QF_{f\,a} \right)^{-\rho_a^{va}} \right)^{-1} \cdot \delta_{f\,a}^{va} \cdot \left(\alpha_{f\,a}^{vaf} \cdot QF_{f\,a} \right)^{-\rho_a^{va} - 1} \tag{A4}$$

$$QA_a = \alpha_a^{a} \cdot \left(\sum_{f \in F} \delta^{a}_{\ a} \cdot (QVA_{\ a})^{-\rho_a^{va}} + \left(1 - \delta^{a}_{\ a}\right) \cdot (QINTA_{\ a})^{-\rho_a^{va}} \right)^{-\frac{1}{\rho_a^{va}}} \tag{A5}$$

$$PA_a \cdot (1 - ta_a) \cdot QA_a = PVA_a \cdot QVA_a + PINTA_a \cdot QINTA_a \tag{A6}$$

$$QXAC_{a\,c} = \theta_{a\,c} \cdot QA_a \tag{A7}$$

$$PA_a = \sum_{c \in C} PXAC_{ac} \cdot \theta_{ac} \tag{A8}$$

$$QX_c = \alpha_c^{ac} \cdot \left(\sum_{a \in A} \delta_{a\,c}^{ac} \cdot QXAC_{a\,c}^{\ -\rho_c^{ac}} \right)^{-\frac{1}{\rho_c^{ac} - 1}} \tag{A9}$$

$$PXAC_{a\,c} = PX_c \cdot QX_c \left(\sum_{a \in A'} \delta_{a\,c}^{ac} \cdot QXAC_{a\,c}^{-\rho_c^{ac}} \right)^{-1} \cdot \delta_{a\,c}^{ac} \cdot QXAC_{a\,c}^{-\rho_c^{ac} - 1} \tag{A10}$$

$$PER_{c\,r} = pwer_{c\,r} \cdot EXR - \sum_{c' \in CT} PQ_c \cdot icer_{c'c\,r} \tag{A11}$$

$$QE_c = \alpha_c^{e} \cdot \left(\sum_{r \in R} \delta_{c\,r}^{e} \cdot (QER_{c\,r})^{-\rho_c^{e}} \right)^{-\frac{1}{\rho_c^{e}}} \tag{A12}$$

$$\frac{PER_{c\,r}}{PE_c} = QER_{c\,r} \cdot \left(\sum_{r' \in R} \delta_{c\,r'}^{e} \cdot \left(QER_{c\,r'} \right)^{-\rho_c^{e}} \right)^{-1} \cdot \delta_{c\,r}^{e} \cdot (QER_{c\,r})^{-\rho_c^{e} - 1} \tag{A13}$$

$$PE_c = pwe_c \cdot EXR - \sum_{c' \in CT} PQ_c \cdot ice_{c'c} \tag{A14}$$

$$QX_c = \alpha_c^{t} \cdot \left(\delta_c^{t} \cdot QE_c^{\rho_c^{t}} + \left(1 - \delta_c^{t}\right) \cdot QD_c^{\rho_c^{t}} \right)^{\frac{1}{\rho_c^{t}}} \tag{A15}$$

$$\frac{QE_c}{QD_c} = \left(\frac{PE_c}{PDS_c} \cdot \frac{1 - \delta_c^{t}}{\delta_c^{t}} \right)^{\frac{1}{\rho_c^{t} - 1}} \tag{A16}$$

$$QX_c = QD_c + QE_c \tag{A17}$$

$$PX_c \cdot QX_c = PDS_c \cdot QD_c + PE_c \cdot QE_c \tag{A18}$$

$$PDD_c = PDS_c + \sum_{c' \in CT} PQ_{c'} \cdot icd_{c'c} \tag{A19}$$

$$PMR_{c\,r} = pwmr_{c\,r} \cdot (1 + tmr_{c\,r}) \cdot EXR - \sum_{c' \in CT} PQ_c \cdot icmr_{c'c\,r} \tag{A20}$$

$$QM_c = \alpha_c^{m} \cdot \left(\sum_{r \in R} \delta_{c\,r}^{m} \cdot (QMR_{c\,r})^{-\rho_c^{m}} \right)^{-\frac{1}{\rho_c^{m}}} \tag{A21}$$

$$\frac{PMR_{c\,r}}{PM_c} = QMR_{c\,r} \cdot \left(\sum_{r' \in R'} \delta_{c\,r'}^{m} \cdot \left(QMR_{c\,r'} \right)^{-\rho_c^{m}} \right)^{-1} \cdot \delta_{c\,r}^{m} \cdot (QMR_{c\,r})^{-\rho_c^{m} - 1} \tag{A22}$$

$$PM_c = pwm_c \cdot (1 + tm_c) \cdot EXR + \sum_{c' \in CT} PQ_{c'} \cdot icm_{c'\,c} \tag{A23}$$

(A24)

Table 7 (continued)

$$QQ_c = \alpha_c^q \cdot \left(\delta_c^q \cdot QM_c^{-\rho_c^q} + \left(1-\delta_c^q\right) \cdot QD_c^{-\rho_c^q} \right)^{-\frac{1}{\rho_c^q}}$$

$$\frac{QM_c}{QD_c} = \left(\frac{PDD_c}{PM_c} \cdot \frac{\delta_c^q}{1-\delta_c^q} \right)^{\frac{1}{1+\rho_c^q}} \tag{A25}$$

$$QQ_c = QD_c + QM_c \tag{A26}$$

$$PQ_c \cdot (1 - tq_c) \cdot QQ_c = PDD_c \cdot QD_c + PM_c \cdot QM_c \tag{A27}$$

$$QT_c = \sum_{c' \in C'} \left(icm_{c\ c'} \cdot QM_{c'} + icmr_{c\ c'} \cdot QMR_{c'} + ice_{c\ c'} \cdot QE_{c'} + icer_{c\ c'} \cdot QER_{c'} + icd_{c\ c'} \cdot QD_{c'} \right) \tag{A28}$$

$$\overline{CPI} = \sum_{c \in C} PQ_c \cdot cwts_c \tag{A29}$$

$$DPI = \sum_{c \in C} PDS_c \cdot dwts_c \tag{A30}$$

Institutional incomes and domestic demand equations

$$YF_f = \sum_{a \in A} WF_f \cdot \overline{WFDIST}_{f\ a} \cdot QF_{fa} \tag{A31}$$

$$YIF_{i\ f} = shif_{i\ f} \cdot [YF_f - trnsfr_{row\ f} \cdot EXR] \tag{A32}$$

$$YI_i = \sum_{f \in F} YIF_{i\ f} + \sum_{i' \in INSDNG'} TRII_{i\ i'} + trnsfr_{i\ gov} \cdot \overline{CPI} + trnsfr_{i\ row} \cdot EXR \tag{A33}$$

$$TRII_{i\ i'} = shii_{i\ i'} \cdot (1 - MPS_{i'}) \cdot \left(1 - \overline{tins}_{i'}\right) \cdot YI_{i'} \tag{A34}$$

$$EH_h = \left(1 - \sum_{i \in INSDNG} shii_{i\ h} \right) \cdot (1 - MPS_h) \cdot \left(1 - \overline{tins}_h\right) \cdot YI_h \tag{A35}$$

$$PQ_c \cdot QH_{c\ h} = PQ_c \cdot \gamma_{ch}^m + \beta_{ch}^m \cdot \left(EH_h - \sum_{c' \in C} PQ_{c'} \cdot \gamma_{c'h}^m \right) \text{ (See section 3.1 for health)} \tag{A36}$$

$$QINV_c = IADJ \cdot \overline{qinv}_c \tag{A37}$$

$$QG_c = \overline{GADJ} \cdot \overline{qg}_c \tag{A38}$$

$$EG = \sum_{c \in C} PQ_c \cdot QG_c + \sum_{i \in INSDNG} trnsfr_{i\ gov} \cdot \bar{CPI} \tag{A39}$$

$$YG = \sum_{i \in INSDNG} \overline{tins}_i \cdot YI_i + \sum_{a \in A} ta_a \cdot PA_a \cdot QA_a + \sum_{c \in CMNR} tm_c \cdot pwm_c \cdot QM_c \cdot EXR + \sum_{r \in R} \sum_{c \in CMR} tmr_{cr} \cdot pwmr_{cr} \cdot QMR_{cr} \cdot EXR + \sum_{c \in C} tq_c \cdot PQ_c \cdot QQ_c + \sum_{f \in F} YF_{gov\ f} + trnsfr_{gov\ row} \cdot EXR \tag{A40}$$

System constraints and macroeconomic closures

$$QQ_c = \sum_{a \in A} QINT_{c\ a} + \sum_{h \in H} QH_{ch} + QG_c + QINV_c + qdst_c + QT_c \tag{A41}$$

$$\sum_{a \in A} QF_{f\ a} = QFS_f \tag{A42}$$

$$QFS_f / QFS_f^0 = \left(RWF_f / RWF_f^0 \right)^{etals_f} \tag{A43}$$

$$RWF_f = \left(\frac{YF_f}{QFS_f} \right) / \left(\frac{CPI}{CPI^0} \right) \tag{A44}$$

$$YG = EG + GSAV \tag{A45}$$

$$\sum_{c \in CMNR} pwm_c \cdot QM_c + \sum_{r \in R} \sum_{c \in CMR} pwmr_{cr} \cdot QMR_{cr} \cdot \sum_{f \in F} trnsfr_{rowf} = \sum_{c \in CENR} pwe_c \cdot QE_c + \sum_{r \in R} \sum_{c \in CER} pwer_{cr} \cdot QER_{cr} + \sum_{i \in INSD} trnsfr_{i\ row} + FSAV \tag{A46}$$

$$\sum_{i \in INSDNG} MPS_i \cdot \left(1 - \overline{tins}_i\right) \cdot YI_i + GSAV + EXR \cdot FSAV = \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c \tag{A47}$$

$$MPS_i = \overline{mps}_i \cdot (1 + MPSADJ) \tag{A48}$$

Capital accumulation and allocation equations

(A49)

Table 7 (continued)

$$AWF^a_{f\,t} = \sum_a \left[\left(\frac{QF_{f\,a\,t}}{\sum_{a'} QF_{f\,a'\,t}} \right) \cdot WF_{f\,t} \cdot WFDIST_{f\,a\,t} \right]$$

$$\eta^a_{f\,a\,t} = \left(\frac{QF_{f\,a\,t}}{\sum_{a'} QF_{f\,a'\,t}} \right) \cdot \left(\beta^a \cdot \left(\frac{WF_{f,t} \cdot WFDIST_{f\,a\,t}}{AWF^a_{f\,t}} - 1 \right) + 1 \right) \tag{A50}$$

$$\Delta K^a_{f\,a\,t} = \eta^a_{f\,a\,t} \cdot \left(\frac{\sum_c PQ_{c\,t} \cdot QINV_{c\,t}}{PK_{f\,t}} \right) \tag{A51}$$

$$PK_{f\,t} = \sum_c PQ_{c\,t} \cdot \frac{QINV_{c\,t}}{\sum_{c'} QINV_{c'\,t}} \tag{A52}$$

$$QF_{f\,a\,t+1} = QF_{f\,a\,t} \cdot \left(1 + \frac{\Delta K^a_{f\,a\,t}}{QF_{f\,a\,t}} - \upsilon_f \right) \tag{A53}$$

$$QFS_{f\,t+1} = QFS_{f\,t} \cdot \left(1 + \frac{\sum_a \Delta K_{f\,a\,t}}{QFS_{f\,t}} - \upsilon_f \right) \tag{A54}$$

Productivity growth

$$\alpha^{va}_a(t+1) = \alpha^{va}_a(t) \left(1 + \vartheta \sum_{h=1}^{G} \frac{\Delta(P_{health}\ (h,t) Q_{health}(h,\ t))}{P_{health}\ (h,\ t) Q_{health}\ (h,\ t-1)} \left(\boldsymbol{H}^h_c(t) \right)^{\left(1 - 1_{[\Delta(PQ)>0]}\right)} \left(1 - \boldsymbol{H}^h_c(t) \right)^{1_{[\Delta(PQ)>0]}} \right) \tag{A55}$$

Source: Adapted from Lofgren et al. (2002) and Thurlow (2004)

CET constant elasticity of transformation, *CES* constant elasticity of substitution, *CPI* consumer price index, *FCU* foreign currency unit, *LCU* local currency unit

Table 8 Estimation of the elasticity of productivity with respect to health expenditures ϑ

Variables	MMEL-2SRI	2SLS
Land	0.418***	0.380***
	(0.071)	(0.054)
Fertilizer	0.0297**	0.0445***
	(0.0124)	(0.0077)
Capital	0.0343***	0.0276***
	(0.008)	(0.009)
Labor	0.0208*	0.0159*
	(0.0108)	(0.008)
Health spending (Ψ): ϑ	0.111***	0.117***
	(0.0318)	(0.034)
Ψ residual	−0.0128	
	(0.010)	
Constant: ς	0.495**	0.484**
	(0.215)	(0.223)
Observations	1,499	1,499
Log-pseudo likelihood	−2567.88	
$\sigma(\boldsymbol{u}_0)$	0.313	
	(0.093)	
Hansen J-statistic (*P* value)		0.149
Kleibergen-Paap Wald rank *F* statistic		16.08
Kleibergen-Paap rank LM statistic (*P* value)		0.00

The dependent variable is the output. The variables are in logarithm. The first step results are available but not reported. The instruments for health expenditures are: age of household head, education of household head, private health center frequentation, house ownership, radio, improved toilet, type of activity, wall material, use of mosquitoes prevention devices, and vaccine. "Ψ residual" represents the residual from this regression. The regressions presented in Table 8 are the logarithm transformations of the following production function: $y = A \prod_{i=1}^{n} x_i^{\beta_i}$ with $\log A = \alpha_0 + \vartheta\ \Psi + \mu_0$, y is the output, x_i the traditional inputs and Ψ the health spending. The exogenous shock $\mu(h, t_0)$ is calibrated using the sum of the residuals "Ψ residual" across the household groups. It is expressed in the SAM unit and is distributed as follows: rural agricultural poor (3.67), rural agricultural rich (5.20), rural non-agricultural poor (3.51), rural non-agricultural rich (8.87), urban agricultural poor (0.18), urban agricultural rich (0.87), urban non-agricultural poor (3.50), and urban non-agricultural rich (14.62)

MMEL multilevel mixed-effects linear regression, *2SRI* two-stage residual inclusion, *2SLS* two-stage least square

Robust-clustered standard errors in parentheses ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 9 Poverty (P^0) evolution for all the simulations

	BAU	S_1	S_2	S_3	S_4	S_5	S'_1	S'_2	S'_3	S'_4	5	S''_1	S''_2
2011	46.71	46.71	46.71	46.71	46.71	46.71	46.71	46.71	46.71	46.71	46.71	46.71	46.71
2020	39.65	38.15	37.39	37.76	37.40	37.47	39.13	37.24	38.52	37.35	39.13	37.96	39.58

Table 10 Health good consumption growth rate *per* household group and for selected simulations

	Initial value	*BAU*	S_1	S_2	S_3	S_4	S_5	S'_1	S''_1	S''_2
Rural agricultural poor	5.20	3.02	3.11	3.18	3.12	3.16	3.13	3.06	3.05	3.72
Rural agricultural rich	4.21	2.96	3.08	3.14	3.09	3.12	3.10	3.02	3.00	3.66
Rural non-agricultural poor	5.64	2.89	3.10	3.15	3.11	3.14	3.13	2.99	2.94	3.58
Rural non-agricultural rich	14.01	2.96	3.23	3.28	3.24	3.27	3.26	3.10	3.01	3.67
Urban agricultural poor	0.84	1.53	1.92	2.02	1.93	1.96	1.94	1.72	1.59	2.01
Urban agricultural rich	1.45	3.28	3.29	3.36	3.29	3.35	3.35	3.28	3.41	3.87
Urban non-agricultural poor	9.40	3.34	3.50	3.59	3.53	3.58	3.58	3.42	3.49	3.94
Urban non-agricultural rich	59.18	3.40	3.63	3.71	3.77	3.70	3.70	3.52	3.53	4.00

Source: the authors

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