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Modeling the Macroeconomic Effects of Disease: Extension and Application in the context of Senegal

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Abstract

Despite the fact that the low- and middle-income countries that are most affected by the Non-communicable diseases have a net capital inflows-to-GDP ratio that represents a significant part of the investment rate, the existing models that quantify the economic burden of disease do not account for the fact that the diseases affect the nets capital inflows-to-GDP ratio. This paper proposes a framework for the analysis of the macroeconomic impact of non-communicable diseases, building upon a Solow-style model. It additionally accounts for i) the fact that the diseases affect the nets capital inflows-to-GDP ratio through the interest rate differential and ii) the education pertaining to the efficiency of labor alongside experience and morbidity. We have applied our methodology to the context of Senegal. The total losses associated with non-communicable diseases over the period 2015--2035 amount to US$ 23 billion. Without taking into consideration the influence of diseases on net capital inflows-to-GDP ratio, total losses will be underestimated by 2.63 %. Without taking account of education in the earning function, total losses will be overestimated by 2.54 %.

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1 Introduction

Non-communicable diseases (NCDs) are the leading cause of death around the world. They were responsible for 38 million (68 %) of the world's 56 million deaths in 2012 (WHO, 2014). These deaths occur more in low- and middle-income countries. Apart from the pain and suffering that these conditions impose on sick individuals, they generate an enormous macroeconomic burden. During the period of 2011–2025, cumulative economic losses caused by NCDs under a "business as usual" scenario in low- and middle-income countries have been estimated to stand at US$7 trillion (Bloom et al., 2011; WHO, 2014). NCDs are expected to affect economic outcomes through two main channels. First, NCDs reduce effective labor supply through mortality and morbidity. Second, a fraction of the annual NCDs-related medical costs is financed from savings, thereby reducing the ressources that should have been devoted to investment in physical capital.

The approaches to estimating the economic impact of chronic diseases in the literature can be classified into three main categories (Abegunde and Stanciole, 2006). The first is the cost of illness method employed by the majority of study on economic impact of diseases. The impact is obtained by summing the direct and the indirect cost. Direct cost consists of medical costs (service fees, overhead costs, drugs) and non-medical costs (transportation, supplemental foods). Indirect cost includes patients' income losses due to morbidity and premature death. The second approach estimates the value of lost economic welfare (VLW) based on the value of statistical life and the disability-adjusted life years (DALYs). In this approach, the authors utilize the value of a statistical life approach in order to value disability-adjusted life years (DALYs), which captures both mortality and morbidity due to a disease in one metric (Alkire et al., 2015). The common drawback of these two first approaches is that no economic adjustment mechanisms are considered, including the substitution of labor lost due to an illness by capital or other workers (Bloom et al., 2018). The last approach consists of assessing the impact of diseases on the GDP. This approach is applied through the utilization of econometric analysis or simulation analysis. The econometric analysis starts with the Solow standard model and adds to the regressor the prevalence of diseases. The simulation models, also called Value of lost Output (Alkire et al., 2015), measure the macroeconomic impact of diseases by comparing the level of GDP in the situation without diseases and the situation in which diseases occur. Our study falls into the category of simulation approaches.

Several models have been developed in the existing literature in order to evaluate the macroeconomic burden of these diseases. All these models build upon the traditional growth model of Solow (1956). They differ from each other in the modeling of effective labor and dynamic of physical capital. Evaluating the impact of AIDS on the GDP of Tanzania, Cuddington (1993) adds to the labor supply the efficiency of labor, which accounts for morbidity through the loss of productivity due to illness and human capital through the experience of workers. The dynamic of physical capital takes into account both net capital flows and the national saving, which can be reduced by healthcare expenditures. The model of Cuddington (1993) has three principle drawbacks. First, human capital is measured only by the experience of workers despite the importance of the level of education for the human capital, as suggested by the earning function of Mincer (1974). Second, the model assumes that the net capital flow is independent of diseases. However, the disease, by influencing both physical capital stock and the aggregate output, also influences capital productivity and, in turn, the interest rate differential. Since the interest rate differential is a determinant of net capital flows, it is clear that the net capital inflows-to GDP ratio is influenced by NCDs. Third, Cuddington (1993) did not present an explicit way that permits the approximation of labor supply in the counter-factual situation. The model EPIC developed by Abegunde and Stanciole (2006) and Bloom et al. (2013), applicable to NCDs, takes into account mortality and provides a way to approximate the labor supply in the counter-factual situation. For physical capital, savings is expected to be reduced by the direct medical cost. We can point out three main drawbacks of the EPIC model. The model does not account for morbidity, human capital and the capital flows. Bloom et al. (2018) improved the EPIC model by accounting for the two first drawbacks of the EPIC model, which are morbidity and human capital accumulation. However, the net capital inflows and the fact that they are influenced by NCDs are ignored.

In this paper, we extend the model of Cuddington (1993) by taking into account the fact that diseases affect the net capital inflows-to-GDP ratio through the interest rate differential. Among the channels through which NCDs can affect the GDP, the channel of the investment rate—sum of savings rate and net capital inflows-to-GDP ratio—is badly taken into account in existing models. The pioneer model of Cuddington (1993) considers that only the savings rate is influenced by the disease, implying that the net capital inflows-to-GDP ratio is independent of diseases. In other models, Abegunde and Stanciole (2006) and Bloom et al. (2018) consider that the savings rate is influenced by NCDs and maintain the assumption of closed economy of Solow (1956). These assumptions are particularly inappropriate due to the fact that the low- and middle-income countries that are most affected by NCDs have a net capital inflows-to-GDP ratio that represents a significant part of the investment rate. For instance, Cuddington (1993) noted in the case of Tanzania that the investment rate was roughly 21%, which for 10% of the foreign saving rate. In the context of Senegal, we have noted an investment rate of 25.35 %, including 15.35 % of the net capital inflows-to-GDP ratio. In our model, we have pushed further the considerations of the Cuddington (1993) model, which establishes links between diseases, physical capital stock, and aggregate output. These links imply that the net marginal product of capital and thus the real interest rate differential is influenced by the NCDs, which is a determinant of the net inflows-to-GDP ratio (Ndiaye et al., 2017). We have applied our methodology in the context of Senegal and estimated the economic burden of six selected chronic diseases (chronic obstructive pulmonary disease, ischaemic heart disease, ischaemic stroke, lung cancer, larynx cancer, and cavity cancer) over the period 2015-2035.

The paper is organized as follows. Section 2 proposes a new model that builds upon the model of Cuddington (1993) but additionally accounts for i) the fact that the diseases affect the nets capital inflows-to-GDP ratio through the interest rate differential and ii) the education in the efficiency of labor alongside experience and morbidity. Section 3 applies the model to the context of Senegal. The conclusion is presented in the section 4.

2 Model

This model quantifies the economic burden of a particular disease as the difference in GDP between two scenarios. In the status quo scenario, the existing NCDs in the economy affect the aggregate output through the effective labour supply and accumulation of physical capital. In the counter-factual scenario, the disease is eliminated from the beginning of the time period. As in most of the previous works (Cuddington, 1993; Abegunde and Stanciole, 2006; Bloom et al., 2013, 2015; Alkire et al., 2015; Bloom et al., 2018), we assume complete elimination of the disease of interest with zero cost of intervention.

2.1 Production function

Aggregate output, Y_t, is assumed to be produced using Cobb-Douglas technology with constant returns to scale :

$$Y_t = A_t K_t^{\alpha} E_t^{1-\alpha} \tag{1}$$

where E_t represents effective labor supply, K_t the capital stock, A_t the total factors productivity, and α the elasticity of aggregate output with respect to physical capital stock. The parameter

A_t can be seen as a scale factor that is adjusted to fit the projected data obtained from an external source.

The first channel through which the disease acts on aggregate output is its adverse effect on the components of effective labor supply: health, experience level, education level, and size of the labor supply. These considerations are incorporated in the following expression of effective labor supply:

$$E_t = \sum_{i=15}^{64} (1 - z_i a_{i,t})\, h_{i,t} L_{i,t} \tag{2}$$

where $a_{i,t}$ represents the cohort-specific prevalence rate of individuals at age i, $L_{i,t}$ the number of workers of age i at time t, and z_i the fraction of the work year loss per disease-stricken worker as a result of the absence or reduced productivity on the job. For simplicity, we measure[1] z_i by the *disability weight* used in the calculation of the *Years Lost due to disability* (YLD).

The parameter $h_{i,t}$ represents the human capital, and hence the productivity level of laborers of age i without the disease of interest. Average human capital is adversely affected as the worsening disease of interest shifts the age structure in favor of younger, both less-experienced workers and less-educated workers. Based on the earning function of Mincer (1974), we add the education to the experience—which is already only taken into account in Cuddington (1993)—in the human capital as follows:

$$h_{i,t} = exp\left[\rho S_{i,t} + \eta_1(i - 15) + \eta_2(i - 15)^2\right] \tag{3}$$

where ρ is the semi-elasticity of human capital with respect to years of education $(S_{i,t})$ and η_1 and η_2 the semi-elasticities of human capital with respect to experience of the workforce $(i-15)$ and the experience of the workforce squared $(i-15)^2$ respectively.

In the presence of the disease of interest (status quo scenario) and neglecting the migratory balance, the evolution of the number of workers in the status quo scenario is given by

$$L_{i,t} \approx L_{i-1,t-1}(1 - d_{i-1,t-1}) \tag{4}$$

where $d_{i,t}$ is the overall mortality rate of age group i.

Denoted by $d^m_{i,t}$, the mortality rate of population in age group i is due to the disease of interest and by $d^{-m}_{i,t}$ the overall mortality rate due to causes other than the disease of interest. Considering that the product $d^{-m}_{i,t} d^m_{i,t}$ is almost zero, we write as in Bloom et al. (2018) that

$$(1 - d_{i,t}) \approx (1 - d^{-m}_{i,t})(1 - d^m_{i,t}) \tag{5}$$

Following Bloom et al. (2018), we can approximate the counter-factual[2] number $\overline{L}_{i,t}$ of workers of age i at time t by

$$\overline{L}_{i,t} \approx L_{i,t} \prod_{j=1}^{min\{t,i\}} (1 - d^m_{i-j,t-j})^{-1} \tag{6}$$

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[1] In fact z_i does not necessarily lie between 0 and 1 because the loss may be not only in the disease victim's labor but also in the labor of others, such as the diseased victim's spouse (Cuddington, 1993). The author sets a plausible value of z through the following simple calculation: if adult AIDS patients live approximately one and a half years but are absent from work for 286 days, the productivity loss can easily reach 50 percent even if the patients and their family members are fully productive on all the other days. Focusing only on the productivity loss of patient and following how Cuddington (1993) found a rough order of magnitude for z in the case of AIDS-stricken workers, we assume that the annual proportion of labor loss per disease-stricken worker as a result of absence or reduced productivity on the job z_i is equal to *disability weight.*

[2] Hereafter, an overbar indicates that the corresponding variable refers to the counter-factual scenfario

2.2 Physical capital accumulation

We consider in the manner of Cuddington (1993) that in addition to domestic saving, capital accumulation may be financed by foreign capital inflows. This assumption is important in the context of developing countries due to the fact that they have a net capital inflows-to-GDP ratio that represents a significant part of the investment rate. In this framework, physical capital accumulation is given by

$$K_{t+1} = Y_t - C_t - \chi m_t a_t L_t + EN_t + (1-\delta)K_t \tag{7}$$

where Y_t represents the aggregate output measured by GDP, C_t the consumption, m_t the annual disease-related medical costs per patient, a_t the prevalence of disease in the population L_t, $a_t L_t$ the number of patients, EN_t the net capital inflows, and χ the fraction of the annual disease-related medical costs that is financed by savings, δ is the rate of depreciation. Assume that the consumption C_t represents a fraction c_t of the aggregate output, which is the same in the both scenarios. Under this assumption, the counter-factual savings rate is given by $\overline{s}_t = 1 - \overline{c}_t = 1 - c_t$. In addition, the net capital inflows-to-GDP ratio $\tau_t = \dfrac{EN_t}{Y_t}$ is assumed to be determined by the interest rate differential as in the appendix of Ndiaye et al. (2017).

$$\tau_t = \mu_t \left(\alpha \frac{Y_t}{K_t} - \delta - r^* \right) \text{ with } \mu_t > 0 \tag{8}$$

where r^* represents the international interest rate. This relation (8) permits the release of the the assumption of independence between the net capital inflows-to-GDP ratio and disease made by Cuddington (1993). Indeed, since NCDs affect both physical capital and aggregate output, it is obvious that they also affect the net marginal product of capital and therefore the net capital inflows-to-GDP ratio. Thus, the dynamic of physical capital (7) is rewritten as follows:

$$K_{t+1} = \left[s_t + \mu_t \left(\alpha \frac{Y_t}{K_t} - \delta - r^* \right) \right] Y_t + (1-\delta)K_t \tag{9}$$

where s_t represents the status quo savings rate, which is defined as follows:

$$s_t = 1 - \frac{C_t + \chi m_t a_t L_t}{Y_t}$$

In addition to its impact on the number of workers, elimination of the disease also improves the dynamics of capital accumulation. To characterize the latter, we assume as in the previous works (Cuddington, 1993; Abegunde and Stanciole, 2006; Bloom et al., 2013, 2015; Alkire et al., 2015) that the elimination of this disease is done without cost. The dynamic of physical capital is given by

$$\overline{K}_{t+1} = \overline{Y}_t - \overline{C}_t + \overline{EN}_t + (1-\delta)\overline{K}_t \tag{10}$$

Assuming that the consumption C_t represents a fraction of the aggregate output, which is the same in the both scenarios ($\overline{c}_t = c_t$), and that A_t, α, and μ_t are independent of disease, the dynamic of counter-factual physical capital is rewritten as follows:

$$\overline{K}_{t+1} = \left[\overline{s}_t + \mu_t \left(\alpha \frac{\overline{Y}_t}{\overline{K}_t} - \delta - r^* \right) \right] \overline{Y}_t + (1-\delta)\overline{K}_t \tag{11}$$

where

$$\overline{s}_t = s_t + \frac{\chi m_t a_t L_t}{Y_t} \text{ and } \overline{K}_0 = K_0$$

From this equation (11), one remarks that the counter-factual savings rates are always higher than the status quo savings rates ($\overline{s}_t \geqslant s_t$). This comparison is not systematic for the net capital inflows-to-GDP ratio except for the year of the eradication of the disease for which $\overline{\tau}_0 \geqslant \tau_0$. The position of the counter-factual net capital inflows-to-GDP ratio compared to status quo net capital inflows-to-GDP ratio for the next years depends on the extent to which production is affected by NCDs compared to the stock capital.

Our model builds upon the model of Cuddington (1993), as it adopts a similar specification for the aggregate output and takes into account the net capital inflows in the dynamics of physical capital. However, unlike the model of Cuddington (1993), our model allows us to account for i) the fact that the diseases affect the net capital inflows rate through the interest rate differential and ii) variations in human capital for workers in different age groups due to both education and experience. This model also sets itself apart from other models in the literature (Abegunde and Stanciole (2006) and Bloom et al. (2018)) with regard to the taking into account the net capital inflows-to-GDP ratio, which represents a significant part of the investment rate in low- and middle-income countries, which are the most affected by the diseases, especially NCDs.

3 Application for Senegal

3.1 Data sources

For aggregate output, α is set to one-third (e.g. Ndiaye et al., 2017), parameters ρ, η_1 and η_2 come from Echevin and Murtin (2009) and z_i come from WHO (2018). For physical capital accumulation, χ and m are provided by the survey on the cost of disease in Senegal conducted by Consortium pour la Recherche Economique et sociale for evaluating the economic cost of main smoking-related diseases. This survey provides information regarding the medical and non-medical costs for patient, his family and the government. It concerns a convenience sample of 14 senegalese public hospitals on the basis of the level of healthcare service provided and the geographical areas. Three were national hospitals and eleven were provincial hospitals. The survey has collect information from 2001 patients aged 18+ years discharged and diagnosed with any of the six diseases of interest from these hospitals. Following Berlemann and Wesselhöft (2012), initial capital stock is obtained by $K_{2015} = \frac{e^{\hat{\lambda}}}{\delta+\hat{\beta}}$, where $\hat{\beta}$ and $\hat{\lambda}$ come from the regression $ln(I_t) = \lambda + \beta.t + \epsilon$ over the period 2015 ($t = 0$) – 2035 ($t = 20$); s and τ are from public institution for economic prevision of Senegal and δ si set to 0.4 (e.g. Abegunde and Stanciole, 2006). Mortality and prevalence rates are from IHME (2017) and GDP from IFs (2018).

3.2 Results of simulation

Table 1 presents a summary of the impact of NCDs on the rate of investment through the savings rate and the rate of net capital inflows. We report results for the tree diseases for which these parameters have changed. With regard to the rate of savings, over the whole period of the study and for all diseases the counterfactual savings rate is higher than the status quo savings rate. This comes from the fact that in absence of the disease, the fraction of the direct medical cost which should be financed out of saving will be now used for investment in physical capital. For the two most costly diseases (IHD and COPD), the average of counterfactual savings rates is 10.21 % compared to 10 % in a status quo situation. For Ischemic stroke, the average of counterfactual savings rates is 10.06 %. With regard to net capital inflows-to-GDP ratio, the first years after the eradication of diseases are characterized by gains of productivity of physical capital compared to the status quo situation. This results in an increase of net capital inflows-to-GDP ratio which supports the positive effect of the elimination of the disease on the savings rate. For 2015, counterfactual net capital inflows rates are respectively 15.56 %, 15.55% and 15.38 % for IHD, COPD and IS compared to 15.35 % in status quo situation. But this capital productivity gain in the counter-factual situation compared to the status quo situation disappears over time. In 2035, counter-factual net capital inflows rates are respectively 15.30%, 15.27% and 15.32% for IHD, COPD, and IS compared to 15.35% in status quo situation. On average over the period from 2015 to 2035, net capital inflows-to-GDP ratio are 15.38 % for IHD and 15.34% for COPD and IS. So, the average net capital inflows-to-GDP ratio for the IHD in the counter-factual situation is higher than the status quo net capital inflows-to-GDP ratio. The opposite is true for the COPD and IS.

The combination of the effects of the elimination of the disease on the savings rate and the net capital inflow rate gives the effect of the elimination on the investment rate. In 2015, the counter-factual investment rates are respectively 25.82% of 25.80 % and 25.46% for IHD, COPD and IS compared to status quo investment rate of 25.35%. In 2035, the counterfactual investment rates are respectively 25.46 %, 25.45 % and 25.38 % for IHD, COPD and IS compared to the statu quo investment rate of 25.35%. On average over the period from 2015 to 2035, the investment rates are respectively 25.58 %, 25.55 % and 25.40% for IHD, COPD and IS. Thus, the counterfactual average investment rate for IHD, COPD, and IS are higher than the status quo investment rate. This means that, on average, the positive effect of the elimination of the disease in the savings rate over the period 2015-2035 and the positive effect of gains in physical capital productivity on the net capital inflows-to-GDP ratio right after the elimination of diseases outweighs the negative effect of the loss of physical capital productivity on the net capital inflows-to-GDP ratio a few years after their eliminations.

Table 1: **Estimates of effect of some conditions on the saving rate, net capital inflows-to-GDP ratio and investissement rate**

	Saving rate s (%)			Net capital inflows τ (%)			Investment $i = s + \tau$ (%)		
	IHD	COPD	IS	IHD	COPD	IS	IHD	COPD	IS
Status quo		10.00			15.35			25.35	
Estimated in 2015	10.25	10.25	10.08	15.56	15.55	15.38	25.82	25.80	25.46
Estimated in 2035	10.16	10.17	10.05	15.30	15.27	15.32	25.46	25.45	25.38
Average 2015-2035	10.21	10.21	10.06	15.38	15.34	15.34	25.58	25.55	25.40

The table 2 summarizes the effect of the six diseases of interest on GDP in our model. It also compares these results with those obtained with the assumption of the independence between the net capital inflows-to-GDP ratio and disease of interest and those obtained when the human capital is due only to experience (Cuddington, 1993). In 2015, the estimated loss in GDP from the six groups of diseases are US$246.69 million (constant 2011 $). These losses represent 1.42 % of GDP. These losses will increase over time and will reach US$2242.07 million (constant 2011 $) in 2035 for the six diseases. These economic burden will represent 3.73 percent of GDP in 2035.

When we ignore the fact that diseases affect the net capital inflows-to-GDP ratio, on average, the Senegal will annually lose US$1068.65 million over the period compared to US$1093.74 million when the influence of diseases on the net capital inflows-to-GDP ratio is taken into account. When we ignore the fact that diseases affect the net capital inflows-to-GDP ratio, undiscounted cumulative losses associated with these six conditions is US$22441.59 million

Table 2: Estimates of GDP loss due to cardiovascular diseases, chronic respiratory diseases, cancer conditions over the period 2015–2035 in 2011 $US (million)

	Our model*	$\overline{\tau} = \tau = 15, 35$	$\rho = 0$
Estimated GDP loss in 2015	246.69 (1.42)	246.69	253.43
Estimated GDP loss in 2035	2242.07 (3.73)	2262.70	2312.76
Average annual loss in GDP	1093.74 (2.9)	1068.65	1125.55
Accumulated GDP loss (2015-2035)	22968.59	22441.59	23636.64

*: ()=% of GDP

over the period 2015-2035 compared to US$22968.59 million when the influence of diseases on the net capital inflows-to-GDP ratio is taken into account. So, we can remark that the consequence of neglecting the influence of diseases on the net capital inflows-to-GDP ratio is an under-estimation of the total economic burden of selected diseases in this case of study. This consequence come from the fact that the positive effect of gains in physical capital productivity on the net capital inflows-to-GDP ratio in the first years of the elimination of the selected diseases outweighs the negative effect of the loss of physical capital productivity on the net capital inflows-to-GDP ratio a few years after their eliminations.

When the hypothesis according to which the human capital is due only to experience as in Cuddington (1993) is made, the differences in the results with our situation are included in table 2. So, we redid the estimations with a semi-elasticity of human capital with respect to years of schooling equals to zero in both scenarios. When we ignore the role of education in human capital, on average, the Senegal will annually lose US$1125.55 million over the period compared to US$1093.74 million when the role of education in human capital is taken into account. When we ignore the role of education in human capital, on average, undiscounted cumulative losses associated with these six conditions is US$23636.64 million over the period 2015-2035 compared to US$22968.59 million when the role of education in human capital is taken into account. So, we can remark that the consequence of neglecting the role of education is an over-estimation of economic burden of selected diseases in the case of Senegal. This consequence come from the fact that the diseases of interest shift the age structure in favor of younger (more-educated workers) and in disfavour of older (less-educated workers) in the case of Senegal.

Undiscounted cumulative losses associated with these six groups of disease is US$22968.59 million over the whole period (2015 to 2035). Among these diseases, IHD, COPD and IS, are the three most costly with US$11682.35 million, US$8759.29 million and US$1956.96 million respectively. On average, Senegal will annually lose US$1093.74 million over the period. These economic burden represent 3.73 percent of GDP in 2035.

4 Conclusion

This paper proposes a model that quantifies the economic burden of a particular disease as the difference in GDP between two scenarios: a counter-factual scenario in which the disease is eliminated from the beginning of the time period and a status quo scenario with the presence of the disease. The model builds upon the Solow-style model of Cuddington (1993) while additionally accounting for i) the fact that the diseases affect the nets capital inflows-to-GDP ratio through the interest rate differential and ii) the education in the efficiency of labor alongside of experience and morbidity. We apply our approach to calculate the economic impact of selected NCDs. The estimated loss in national income in Senegal from the six diseases of the study are

US$246.69 million (constant 2011 $). These losses represent 1.42% of the GDP in 2015 and will reach US$2242.07 million (constant 2011 $) in 2035 or 3.73 % of the GDP. Undiscounted cumulative losses between 2015 and 2035 will be US$22968.59 million (constant 2011 $) and the average year loss over this period is US$1093.74 million (constant 2011 $). Losses from ischemic heart disease, COPD, and stroke are 0.68 %, 0.64 %, and 0.10 % of GDP in 2015 and 1.92 %, 1.38 %, and 0.32 % in 2035.

The present study has several drawbacks. First, the incorporation of education is done by supposing that its level is the same in the both scenarios. Demographic change will probably affect this education level. Second, we do not express the human capital in the dynamic equation like physical capital. Doing so, we do not take into account the impact of treatment cost on this human capital.

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