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# Global warming, intermediary market power, and agricultural exports: Evidence for cotton and cashew nuts in West Africa

This research aims at analysing the extent to which climate change affects cotton and cashew nuts production and exports in West African countries in the presence of intermediary market power. To that end, the paper uses a combination of approaches to calibrate a price endogenous regional bio-economic optimisation model and handles uncertainties inherent to future socio-economic scenarios through Monte Carlo simulations. The results show that the effects of climate change on cotton and cashew nuts land use are mixed under the two simulated climate change scenarios. In fact, the effects vary across countries, ranging from experiencing only a decline, or only an increase to both a decline and an increase in land use. Similarly, the effects of climate change on the quantities of cotton and cashew nuts exported are also mixed, with the positive effects being more pronounced for cotton. Simulations of reductions in the market power exerted by intermediaries on cotton producers also show that such a scenario could to some extent mitigate the negative effects of climate change on cotton exports for some countries. Therefore, actions that include corrections to cotton market imperfection could be undertaken to mitigate the negative effects of climate change on cotton and cashew nuts production in West Africa.

**Keywords:** climatic change, intermediary market power, Monte Carlo simulations, price endogenous partial equilibrium, agricultural exports

**JEL classifications:** Q15, Q17

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## Introduction

Climate change constitutes the most significant of all environmental externalities, and is particularly pernicious as it involves so many activities of daily life, and affects the entire planet (Nordhaus, 2019). Thus, this environmental externality is acknowledged in the economics literature as affecting both agricultural production and trade (Dallmann, 2019; Nordhaus, 2019). The effects of climate change on agricultural production could continue without adequate adaptation as well as mitigation strategies (Huang *et al.*, 2011). Meanwhile, agricultural trade could also be affected by changes in climatic conditions (Dallmann, 2019). Indeed, climate change might affect trade both indirectly – via its impact on production – and directly by impacting transport and distribution channels (Dellink *et al.*, 2017), and also prices (Willenbockel, 2012). It should be noted that developing countries are typically characterised – economically speaking – by the export of raw agricultural products and also tend to regulate the domestic markets of those products insofar as these constitute the means of foreign exchange generation (Mbaye *et al.*, 2018; Delpeuch, 2009). However, in the absence of competition, intermediary firms could exert market power and hold prices above marginal costs (De Loecker *et al.*, 2020; Chen and Yu, 2019). Thus, imperfect competition is characterised by higher prices relative to the perfect competition benchmark and this has welfare and resource allocation implications. In fact, farmers growing cash crops in developing countries do not directly export these to the international markets. Instead, there are intermediaries that buy these crops from farmers and even transform them partially before shipping them abroad. Therefore, the intermediaries often exert oligopsonitic market power on farmers that could affect production and the quantities traded, over and above the effects of climate change.

The international trade literature acknowledges that countries must be integrated into the world economy. Differences in technology (Ricardo and Ricardo-Viner) and differences in endowments of production factors (Heckscher-Ohlin-Samuelson) are traditionally emphasised by trade theorists as determinants of international trade (Jones, 2014; Huang *et al.*, 2011; Morrow, 2010). In fact, under the international trade paradigm, endowments in resources drive product specialisation, all else being equal, and countries specialise in the production and the export of products requiring intensive use of relatively abundant resources. It should be noted that agriculture is highly sensitive to the climate, particularly in areas where irrigation is not widespread. Therefore, due to the climate change threat, crop yields are expected to fall in the future in many regions for many crops. The fall in crop yields could affect production levels and influence international trade, as well as trade within countries. In fact, the potential changes in patterns of geographical specialisation of production are driven by changes in the returns to factors of production employed in agriculture such as land (Huang *et al.*, 2011). These returns would be negatively affected in the agricultural sector, this mostly being so in low-latitude countries, where the impacts of climate change on agriculture are expected to be more pronounced (Nordhaus, 2019; Rosenzweig and Parry, 1994).

The Intergovernmental Panel on Climate Change (IPCC) points out that the implications of climate change on agriculture are expected to result in higher trade flows from mid- to high-latitude products (e.g. cereal and livestock) to low latitudes which are expected to experience a fall in yields (Huang *et al.*, 2011; IPCC, 2007). The West African countries are among the countries around the world that are expected to be adversely affected by global climatic change (Nordhaus, 2019). In addition, these countries rely on the exports of raw agricultural products such as cocoa, coffee, cotton, and cashew nuts due to their thin industrial sector. For instance, cotton constitutes an important crop for some West African countries such as Benin, Burkina Faso, Mali and Togo which are among the leading African exporters. This crop is considered as a 'white gold' for these countries. The evidence shows that most of these countries are specialised in cotton production (Mbaye *et al.*, 2018).

In addition, some West African countries may desire to invest in cashew nuts production for export diversification purposes, as Côte d'Ivoire has done recently. Certainly, integration into the world economy represents a powerful means for countries to promote economic growth, development, and poverty reduction (World Bank, 2007). Moreover, cotton markets in the West African countries have been strongly regulated by governments (Mbaye *et al.*, 2018; Staritz and Tröster, 2015). As a result, the cotton sector in West African countries is characterised by a high degree of vertical integration (Staritz and Tröster, 2015). Even if the market structure of cotton has evolved with the liberalisation since 1990, there is still a presence of market power exerted by intermediaries to the detriment of producers. Thus, the cotton markets in these countries are still somehow characterised by imperfect competition. In fact, the typology differentiates between national monopolies in Mali and Senegal, local monopolies or 'concessions' in Burkina Faso, Côte d'Ivoire and Ghana, and hybrid systems in Benin (Delpeuch, 2009). The situation of the market structure of cashew nuts is similar to that of cotton (Ton *et al.*, 2018); although countries such as Benin in the past largely left the cashew sector to market forces, the paradigm has since changed and the State is very actively intervening in this sector.

This research aims at analysing the extent to which climate change affects cotton and cashew nuts production and exports in West African countries. Meanwhile, a combination of approaches for a regional bio-economic model calibration is developed; uncertainties inherent to future socio-economic conditions are introduced through Monte Carlo simulations and intermediary market power exertion in cotton domestic markets is taken into account. Specifically, this paper seeks to (i) evaluate the implications of global climatic change on cotton and cashew nuts land use, (ii) assess the effect of climate change on the quantities of cotton and cashew nuts exported, and (iii) investigate the extent to which the reduction of intermediary market power in cotton domestic markets would mitigate the effects of climate change on cotton and cashew nuts exported quantities. To our knowledge, no study investigating individual export crops in the African context has yet taken market imperfection into account in the assessment of climate change effects on agricultural trade. Most of the previous literature accounting for imperfect competition is related to developed countries (e.g. Baker *et al.*, 2018; Kawaguchi *et al.*, 1997), to global models and models at the level of Sub-Saharan Africa without there being any disaggregation showing the individual cash crops (e.g. Calzadilla *et al.*, 2013). In addition, the previous literature tends to focus on the effects of climate change on agricultural trade (e.g. Egbendewe *et al.*, 2017). This paper therefore contributes to the existing literature by filling a gap relating to the impacts of climate change on the international trade in agricultural commodities.

To reach these objectives, a bio-economic optimisation model is developed for 13 West African countries. The model includes 21 crops that are not traded internationally by these countries, four crops that are mainly produced for export, and rice importation. This paper makes several new contributions to the existing literature. First, the exertion of market power by intermediaries in domestic markets for cotton has been modelled based on econometric regressions. Second, the optimisation model has been calibrated by drawing on the calibration techniques of computable general equilibrium (CGE) models and the positive mathematical programming (PMP) approach. Third, future socio-economic scenarios are included through the use of Monte Carlo simulations, with adaptive expectations being assumed. Fourth, it contributes to our understanding of the international trade in cotton and cashew nuts, a domain which has not been studied in the previous literature, yielding insights as to the impacts of climate change on the export of these products from West Africa.

The remainder of the paper is organised as follows. The modelling techniques developed in the paper are presented in Section 2. Section 3 presents the findings of the simulations and discusses these findings in the light of earlier literature. The last section concludes the paper and comments on the policy implications.

## Materials and methods

Researchers face challenges in building economic models that take both the plant growth process and economic optimisation behaviour across the supply chain into account in order to develop simulations capable of informing decision makers in relation to critical agricultural, energy and environmental policies. In fact, several agricultural economic models such as the Forestry and Agricultural Sector Optimisation Model (FASOM) with its subsequent version featuring greenhouse gas emissions (McCarl and Schneider, 2001) as well as the Global Biosphere Model (GLOBIOM) (Havlík *et al.*, 2013; Havlík *et al.*, 2011) among others have been built for such a purpose. This paper extends these modelling efforts, in order to suggest improvements to the calibration aspects as well as better ways to handle future socio-economic conditions, while accounting for market imperfections in the markets for some products. Hence, this research relies on a bio-economic modelling framework involving a representative risk-neutral economic agent in an integrated assessment setting. Biophysical and geographic information system (GIS) data are integrated into a regional, price-endogenous mathematical programming model. Crop yields are supplied to the optimisation model by an econometric crop yields simulator. The GIS component supplies to the bio-economic model parameters related to available land (for the 3 soil types within 39 agro-climatic zones - ACZs).

The economic component is a spatially-explicit price-endogenous mathematical programming model which uses production costs and biophysical parameters from the first two components, while still accounting for imperfect competition in cotton markets. The whole model is then optimised to determine optimal land allocations among available cropping systems so as to maximise the net present value of

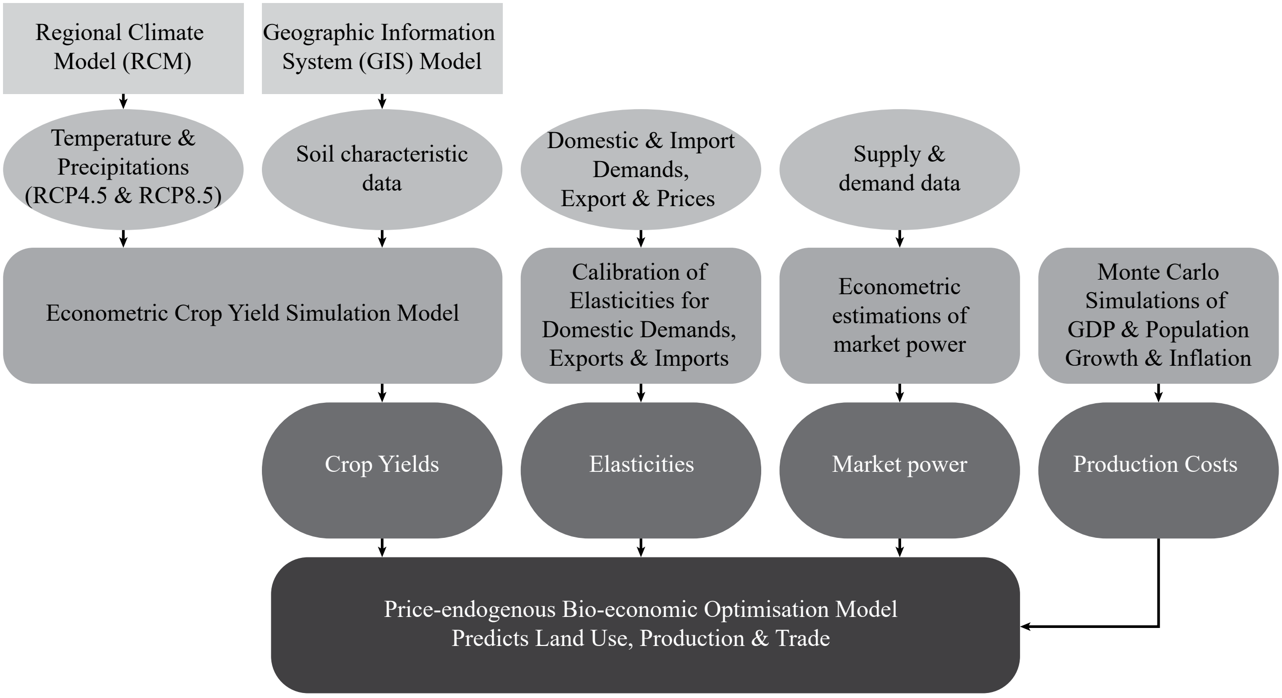


**Figure 1:** Structure of the regional bio-economic optimisation model.
Source: Own composition

the sum of consumers' and producers' surpluses. Figure 1 describes the general structure of the bio-economic model.

## Crop yield model

The paper adopts an econometric regression approach to estimate crop yields following Chang (2002), as this research does not aim to estimate environmental outcomes like agricultural runoffs and emissions. In this framework[4], it is assumed that crop yields depend only on climate and soil conditions. This assumption is valid due to the characteristics of agriculture in West African countries. In these countries, agriculture is mostly rain-fed, and the use of fertilisers and mechanisation is not widespread and remains marginal. This research makes use of the average 2010 crop yields from the 39 ACZs under three soil types as well as of long-run (1981-2010; 30 years) average temperature and rainfall from May to November, given that these are the major climatic factors prevailing during the phenological stages of crop development. Nevertheless, technological change may induce variations under similar environmental conditions; consequently, this research adjusts the crop yields to take into account the effects of technological change. In fact, even with an unchanged climate, crop yields do not remain constant. The crop yields model used to estimate the yields of each of the 25 crops included in the bio-economic model is specified as follows:

$$Yield_i = f(temp_i, temp_i^2, vtemp_i, rain_i, rain_i^2, vrain_i, clay_i, loam_i) + \varepsilon_i \quad (1)$$

where *Yield* refers to crop yield per ha, *temp* is the average monthly temperature (in degrees Celsius), *vtemp* refers to the monthly variability of the temperature captured by the variance from April to November, *rain* stands for total rainfall from April to November (in mm), *vrain* is the monthly variability of rainfall captured by the variance, *clay* and *loam* are dummy variables that help to account for the effect of land characteristics on crop yields, and *i* stands for the ACZ. The non-linear effects of temperature and rainfall are included in equation (1) through their quadratic terms to be consistent with the notion of the physiological optimum (McCarl *et al.*, 2008; Chang, 2002; Kaufman and Seth, 1997). Moreover, the implications of the variability of climate factors on crop yields are taken into account by including temperature and rainfall variations, since their omission may lead to biased estimations (Mendelsohn *et al.*, 1996). The estimation results by the ordinary least squares (OLS) of cotton and cashew nuts yield regressions are presented in Table A1 of the Appendices. Future crop yields are simulated based on the estimation results of crop yields. It should be noted that, as previously mentioned, future crop yields are adjusted for technological change that allows an average annual yield increase of 1% (Lokonon *et al.*, 2019; Egbendewe *et al.*, 2017), implying a doubling of crop yields after 70 years. This adjustment is in line with the deceptive technological change rate observed in the West African region's agriculture (Nin-Pratt *et al.*, 2010; Nin-Pratt and Yu, 2008).

## GIS component of the model

This study uses GIS to design a consolidated map of ACZs, soils, land use, and countries. The West African region is divided into 39 ACZs based on homogeneity in

[4] The econometric regressions do not take into account crop rotations and other management practices which may improve or deteriorate environmental conditions, such as the contents of soil nutrients.

weather conditions having the greatest effect on crop growth and yields. ACZs aim more adequately to distinguish among the diversity of practices, particularly in terms of different climates, regarding similar agricultural systems within larger agro-ecological zones (van Wart *et al.*, 2013). In the bio-economic model, agricultural production decisions take place at the ACZ level within the countries. However, in actuality crop production decisions take place at farm level. However, as the ACZ part of a country is the smallest unit based on the GIS component of the model (given that this study does not rely on household surveys), this means that the model considers a farmer at ACZ level within the countries to be representative. This assumption of a representative farmer is consistent with the literature (e.g. Calzadilla *et al.*, 2013; Havlík *et al.*, 2013) and in the case of this study takes advantage of the ACZs within the countries. Nonetheless, country information relating to ACZs is used for the disaggregation of land resources per country and per soil type. Cropland information per ACZs has been obtained from land use maps produced by previous research (FAO, 2015; Sebastian, 2014; van Wart *et al.*, 2013).

## Economic optimisation model

Economic behaviour is modelled from the standpoint of a representative risk-neutral economic agent that is endowed with land resources, and has to choose among a set of crop production activities in order to maximise the combined sum of producers' and consumers' welfare. Under budget constraints, consumers derive utility from the consumption of crops if separable utility functions are assumed. In line with the assumptions made in large agricultural optimisation models (McCarl and Schneider, 2001), demand functions are assumed to take the form of constant elasticity. Vertical supply functions derived from a Leontief production are then used (Chen and Önal, 2012). This paper assumes that all produced quantities are brought to the market, so it does not assume a semi-subsistence agriculture characterised by the fact that only part of the production is marketed and the remainder is self-consumed by the households. Consequently, self-consumption is valued similarly to the part that is marketed. In this framework, the total welfare obtained from the market for each locally produced crop is equivalent to the area underneath the demand curve minus the production costs. Crops such as cashew nuts, cocoa, coffee and cotton are exported, and vertical supply functions are also used for them. However, for these exported crops, producer welfare is derived from constant elasticity export functions. Constant elasticity import demand and export supply functions are assumed for the imported rice, and the domestic welfare derived from rice import is computed as the consumer surplus from these imports. It is important to point out that a partial equilibrium economic model that simulates market clearing prices using price endogenous modelling (McCarl and Spreen, 1980) has been utilised. This modelling approach was originally initiated by Enke (1951) and Samuelson (1952) and was later fully developed by Takayama and Judge (1964). The optimisation problem can be expressed as follows:

$$\begin{aligned}
&\underset{x_{jklmt}}{Max\,\Omega} \sum_t \sum_l \sum_j \sum_k \exp(-\rho t) \\
&\Bigg[\Bigg((1+\theta\lambda_{kt}+\emptyset\eta_{kt})^{t/\epsilon}\int_0^{q_{klt}^d} p_{klt}^d(\cdot)\,dq_{klt}^d - \\
&-\sum_m \pi_{kt}c_{klt}x_{jklmt}\Bigg) + \\
&+\Bigg((1+\theta\lambda_{kt}+\emptyset\eta_{kt})^{t/\epsilon}\int_0^{q_{kt}^r} p_{kt}^r(\cdot)\,dq_{kt}^r - \\
&-(1+\gamma)p_{kt}^r q_{kt}^r\Bigg) + \\
&+\Bigg(\sum_n \{p_{knt}^e q_{knt}^e - \int_0^{q_{kt}^e} p_{knt}^e(\cdot)\,dq_{knt}^e\}\Bigg)\Bigg]
\end{aligned} \tag{2}$$

$$q_{klt}^d = \sum_j \sum_m (\beta_{jkl}x_{jklmt} - \delta_{jkl}x_{jklmt}^2)\ ,\forall\, t,k,l \tag{3}$$

$$q_{knt}^e = \sum_j \sum_m (\psi_{jkl}x_{jklmt} - \alpha_{jkl}x_{jklmt}^2)\ ,\forall\, t,k,n \tag{4}$$

$$\sum_l x_{jklmt} = L_{kjt}, \forall t,k,m,j \tag{5}$$

$$q_{kt}^r + S_{kt}^r = (1+\theta\lambda_{kt}+\emptyset\eta_{kt})^{t/\epsilon} D_{kt}^r, \forall t,k \tag{6}$$

$$\begin{aligned}
&p_{knt}^e = (\varphi_{kn}\omega_{kn}^1 + \omega_{kn}^2)q_{knt}^e + \omega_k^3 Q_{knt}^e + \\
&+\vartheta_{kn}, n = cotton, \forall t,k
\end{aligned} \tag{7}$$

The objective function, equation (2), maximises the total welfare that is the sum over time ($t$), crops ($l$), ACZs ($j$) and countries ($k$) of the welfare of domestically produced crops apart from exported crops (the first parenthesis), the welfare from rice imports (the second parenthesis), and the welfare from exported crops (the third parenthesis). The welfare computed in the first parenthesis is the sum of the areas underneath the demand curves of the domestically produced crops $p_{klt}^d(\cdot)$ minus the total costs over the three soil types ($m$) with  being the unit production cost (per ha). This research indexes the total costs by the inflation rate ($\pi$). In the second part of the objective function (second parenthesis), the welfare from rice imports is computed as the areas underneath the import demand curves $p_{kt}^r(\cdot)$ minus the total value of imports that is subject to the common external tariff (CET) applied in the ECOWAS zone ($\gamma$).

The welfare derived from exported crops (the third parenthesis) is calculated as the sum of the total value of exports minus the areas underneath the export supply curves for the $n$ exported crops. The demand and supply balance for locally produced and consumed crops $q_{klt}^d$ and the exported crops $q_{knt}^e$ are respectively captured by equations (3) and (4). A PMP calibration approach (Howitt, 1995) is used to obtain the quadratic form of the right-hand side of equations (3) and (4), and $\beta,\delta,\psi$ and $\alpha$ are calibration parameters. Equation (5) refers to land demand and supply balance, and equation (6) is rice import demand computed as the residual demand.

The demand is projected into the future using the expression $(1+\theta\lambda_{kt}+\emptyset\eta_{kt})^{t/\epsilon}$ under the assumption that demand grows at the rate of gross domestic product (GDP) growth ($\eta$) and population growth ($\lambda$). $\theta$ and $\emptyset$ are respectively the elasticity of demand coefficients with respect to population and GDP growth. $D_{kt}^{r}$ and $S_{kt}^{r}$ are the base year total rice demand and total domestic rice supply, respectively. Equation (7) equalises price to marginal costs plus a part that depends on market power ($\varphi$) exerted by the intermediaries on cotton producers. The quantity of cotton exported by the intermediaries is captured by $Q_{knt}^{e}$. The market power coefficient ($\varphi$) and the remaining parameters of equation (7) ($\omega^1$, $\omega^2$, $\omega^3$ & $\vartheta$) are obtained from econometric regressions following Bresnahan (1989). The value of the market power coefficient is between 0 and 1. If $\varphi=0$ then, the market is competitive. As its value become greater than 0, $0<\varphi<1$, there is a departure from the competitive equilibrium to a market characterised by imperfect competition. If $\varphi=1$, full monopoly power is being exerted in cotton markets. The parameter $\rho$ is a discount coefficient.

### Calibration and dynamics via Monte Carlo simulations

This paper innovates first through the ways that the calibration of the model is carried out for improvement in the precision of the simulation results. Several efforts have been made in the literature to improve the capability of agricultural sector models to replicate closely the base year data, and escape a corner solution. Thus, the PMP calibration technique has been developed by Howitt (1995) which relies on the hypothesis that crop yields are decreasing functions of cultivated land areas. Other researchers have made many attempts to improve the PMP calibration approach, such as Mérel *et al.* (2011) and Mérel and Bucaram (2010). Moreover, other evidence on calibration methods has been provided from the experience of working with CGE models, which are based on the generalised axiom of revealed preference theorem (Afriat, 1967). For this theorem, if data from choices made by consumers or producers on prices and quantities are observed, then it is certain that these choices are based on rational preferences, and that utility and production functions are well behaved. Consequently, the optimisation problem described above can be solved for the elasticities of demand and supply functions, based on a given set of observed base year data on prices and quantities. This paper operationalises the optimisation problem following the three steps of the quadratic PMP as shown in equations (3) and (4). Thus, the calibration procedure relies both on the revealed preference approach of the CGE models, and the PMP approach. With this calibration method, there is no need for external estimations of the elasticities, and it works with better precision, particularly in an environment with a limited dataset.

Second, the dynamics of the bio-economic model are built through several channels of transmissions. Crop yields, which are one of the future drivers of the model, are projected based on climate scenarios using equation (1). Population and economic growth are then assumed to drive future demand. Finally, future production costs are assumed to be driven by growth in inflation rates. This paper assumes that future realisations of population growth, economic growth and inflation rates are drawn randomly from their values in past years. This assumption is made since only past information exists on the population growth, economic growth and inflation, and is equivalent to the hypothesis that the representative agent uses adaptive expectations (Nerlove, 1958) in the prediction of future realisations of these parameters by drawing them from past observations. Therefore, parametric distributions could be estimated from empirical distributions to simulate these parameters through Monte Carlo simulations, with observations of the past years. With this technique, thousands of simulations can be done with thousands of draws, and the values for average key outputs as well as their confidence intervals can be estimated. Nevertheless, this approach increases the computation time, given the number of simulations. The elasticities of demand coefficients with respect to population and GDP growth are obtained from the literature (Regmi and Meade, 2013; Johnson, 1999).

## Empirical results and discussion

The empirical section consists of calibrating the model with data on land use, prices and quantities of the base year which is 2010 (2010 being chosen due to data availability). The time horizon of the model is 2100 with windows of 10 years. The use of the revealed preference approach of the CGE models helps in estimating all the elasticity values (Table 1). This approach, coupled with the PMP technique, has minimised the calibration error of the model; a percentage absolute deviation (PAD) of the calibrated model is about 5.42%. Note that the PAD could have been higher without using the combination of these two calibration approaches. Subsequently, simulated crop yields under the representative concentration pathways (RCP) 4.5 and RCP 8.5, population and economic growth as well as inflation rates projected up to 2100 are introduced into the model to govern the dynamics of the model. Thus, the two climate scenarios are run against a baseline scenario which is assumed to be the business-as-usual (BAU) scenario. In the BAU scenario, technological change is the key element that drives crop yields until the end of the century. These two RCPs are chosen owing to data availability in terms of disaggregation per ACZ.

**Table 1:** Calibrated elasticity of export supply of cashew nuts and cotton.

| | Cashew nuts | Cotton |
|---|---|---|
| Benin | 1.83 | 1.53 |
| Burkina Faso | 1.65 | 1.67 |
| Côte d'Ivoire | 2.03 | 1.55 |
| The Gambia | 1.04 | -- |
| Ghana | 1.72 | -- |
| Guinea | 1.32 | -- |
| Guinea Bissau | 1.57 | -- |
| Mali | 1.27 | 1.47 |
| Nigeria | 1.34 | -- |
| Togo | 1.11 | 1.38 |

Source: Own composition

Monte Carlo simulations are often used to account for uncertainties in outcomes such as future socio-economic scenarios that govern the dynamics of this model. Therefore, the paper uses 31 years' data (1980-2010) on population growth, economic growth, and inflation rates for the 13 West African countries included in the study (Benin, Burkina Faso, Côte d'Ivoire, The Gambia, Ghana, Guinea, Guinea Bissau, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo) from the World Development Indicators. Cape Verde and Liberia which are also members of the Economic Community of West African States (ECOWAS) are not included in the research due to the lack of consistent dataset during the period of study. For the choice of the best parametric distributions, this paper compares the goodness-of-fit between the empirical distributions of the observed data against a set of eight parametric distributions (Egbendewe-Mondzozo *et al.,* 2013). The goodness-of-fit test used penalises the distributions at the tails (Anderson and Darling, 1952). Table A2 of the Appendices reports the selected parametric distributions. Three hundred random draws from these parametric distributions are simulated and averaged for each key output variable under consideration (cashew nuts production and exports, and cotton production and exports under the BAU scenario and the two RCPs). Experimentations show that Monte Carlo simulations above 300 random draws do not change the average values of the key output variables.

These elasticity values suggest that the supply of cashew nuts and cotton exports are elastic in the ten countries studied for cashew nuts and the five for cotton. Countries with no elasticity values reported for cotton do not export it at all. Where cashew nuts elasticity values are concerned, marginal producing countries are also intentionally included as some countries may desire to invest in its production in the future for export diversification purposes, as Côte d'Ivoire has done recently. It is noteworthy that the values of market power coefficients estimated for Benin, Burkina Faso, Côte d'Ivoire, Mali, and Togo amount to 0.006, 0.006, 0.001, 0.001, and 0.134 respectively. This shows that market power is being exerted by intermediaries even if the degree of the power might be low. The highest market power exerted by intermediaries is in Togo, and the lowest is in Côte d'Ivoire and Mali.

## Simulation results under RCP 4.5 relative to the BAU

It should be recalled that in the BAU scenario, no climate effects are assumed, and cotton and cashew nuts yields increase every year from their 2010 values in line with technological change at a rate of 1%. The findings presented here relate to a climate scenario where a moderate level of GHG forcing (moderate climate change) is assumed. To shed light on how they differ from the BAU scenario, the simulation results (land use and exported quantities) under RCP 4.5 are presented relative to the BAU scenario (in percentage terms).

## Cotton simulation results under RCP 4.5 relative to the BAU

Cotton land use tends to be sensitive to moderate climate change (Table 2). In fact, under RCP 4.5, cotton land use might decrease in some years and might increase in some other years relative to the BAU scenario in Benin and Mali. Under this scenario, Mali could experience mainly a drop in cotton land use relatively to the BAU except in the last three decades of the century. In Benin, cotton land use might decline relatively to the BAU in 2020, 2030, 2050 and 2080. At the same time, increased cotton land use might be observed in Burkina Faso, Côte d'Ivoire and Togo relatively to the BAU scenario. As for the exported quantities, the findings suggest that cotton exports from West African countries could experience mixed effects under a moderate climate change scenario (Table 3). Overall, cotton exports are projected to increase in most countries except in Mali and in Benin where exports might decline in some years. These mixed effects (regarding cotton land use and cotton exported quantities) underline the fact that under a medium GHG forcing scenario (RCP 4.5), the distribution of precipi-

**Table 2:** Cotton land use under RCP 4.5 relative to the BAU scenario (%).

| | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|
| Benin | -35.21 | -8.64 | 27.06 | -23.23 | 79.73 | 13.72 | -51.59 | 4.21 | 4.21 |
| Burkina Faso | 23.21 | 33.01 | 39.48 | 47.51 | 49.70 | 41.96 | 29.31 | 20.90 | 15.30 |
| Côte d'Ivoire | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 |
| Mali | -89.33 | -84.77 | -84.58 | -75.91 | -66.79 | -56.99 | 1.88 | 2.97 | 3.39 |
| Togo | 612.42 | 509.48 | 204.78 | 235.04 | 126.96 | 22.49 | 274.26 | 180.53 | 2.98 |

Source: Own composition

**Table 3:** Cotton exports under RCP 4.5 relative to the BAU scenario (%).

| | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|
| Benin | -11.96 | 29.88 | 84.94 | 14.25 | 183.95 | 99.90 | -5.08 | 108.92 | 94.10 |
| Burkina Faso | 41.62 | 60.75 | 72.05 | 85.71 | 103.46 | 116.09 | 128.10 | 119.61 | 92.56 |
| Côte d'Ivoire | 56.40 | 59.12 | 64.18 | 75.22 | 90.42 | 94.43 | 100.60 | 102.09 | 93.57 |
| Mali | -87.71 | -81.40 | -81.30 | -70.72 | -56.68 | -36.81 | 84.92 | 93.77 | 78.37 |
| Togo | 1,221.02 | 1,055.01 | 500.05 | 557.80 | 378.74 | 164.51 | 807.35 | 589.25 | 140.25 |

Source: Own composition

tations may be very random and could cause some countries to have better yields than others (Egbendewe *et al.*, 2017).

## Cashew nuts simulation results under RCP 4.5 relative to the BAU

Cashew nuts land use also exhibits dissimilarities across countries under a moderate climate change scenario relative to the BAU scenario (Table 4). Ghana and Guinea Bissau are expected to face a decline in cashew nuts land use under a moderate climate change scenario relative to the BAU from 2040 to the end of the century and in 2080 and 2090, respectively, and might experience an increase in the other years. Cashew nuts land use would only increase under a moderate climate change scenario in the remaining countries. However, the effects on cashew nuts exports are different compared with those on land use (Table 5). Cashew nuts exports could decline over the simulation period under RCP 4.5 in The Gambia, Guinea, Nigeria and Togo. The effects of a moderate climate change on cashew nuts exports are positive in every period for Benin, Côte d'Ivoire and Mali. Burkina Faso, Ghana and Guinea Bissau could record positive effects as well as negative effects due to moderate climate change, depending on the years.

Moreover, the findings indicate that cashew nuts export patterns are not affected in Senegal. The mixed results across countries underline the random nature of the uneven distribution of rainfall, leading some countries to do better than others. The uneven distribution of rainfall might affect cashew nuts yields and the increase in land use may not be enough to maintain the same level of exports in the BAU scenario in many countries, while other countries gain from their comparative advantage in terms of cashew nuts exports. It should be noted that exported quantities of cashew nuts are more negatively affected by moderate climate change than exported quantities of cotton. This suggests that the share of the West African countries in the world cashew nuts market could decline, everything else being equal.

## Simulation results under RCP 8.5 relative to the BAU

These results correspond to a harsh climate scenario characterised by higher degrees of GHG forcing. The simulation results are presented following the same strategy as with the moderate GHG forcing scenario. That is, the figures for land use and the export of cotton and cashew nuts are presented relative to the BAU scenario and are calculated as the ratio

**Table 4:** Cashew nuts land use under RCP 4.5 relative to the BAU scenario (%).

| | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|
| Benin | 69.60 | 42.42 | 51.89 | 36.13 | 25.25 | 57.73 | 164.29 | 100.99 | 105.32 |
| Burkina Faso | 2.34 | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 |
| Côte d'Ivoire | 33.68 | 24.66 | 18.21 | 13.71 | 11.26 | 8.87 | 4.94 | 4.70 | 4.21 |
| The Gambia | 0.19 | 0.13 | 0.20 | 0.29 | 0.42 | 0.60 | 0.84 | 1.15 | 1.52 |
| Ghana | 0.89 | 169.57 | -9.19 | -8.05 | -5.51 | -5.09 | -3.43 | -1.81 | -0.35 |
| Guinea | 5.23 | 4.64 | 4.49 | 4.40 | 4.34 | 4.29 | 4.27 | 4.22 | 4.21 |
| Guinea Bissau | 10.51 | 13.61 | 1.58 | 26.15 | 14.50 | 12.16 | -2.99 | -6.43 | 23.48 |
| Mali | 4.21 | 4.21 | 4.26 | 4.24 | 4.22 | 4.21 | 4.16 | 4.13 | 4.18 |
| Nigeria | 6.35 | 5.51 | 4.27 | 4.24 | 4.23 | 4.22 | 4.22 | 4.21 | 4.21 |
| Senegal | 8.29 | 5.49 | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 |
| Togo | 14.38 | 6.42 | 4.18 | 13.83 | 4.20 | 4.20 | 4.21 | 4.20 | 4.21 |

Source: Own composition

**Table 5:** Cashew nuts exports under RCP 4.5 relative to the BAU scenario (%).

| | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|
| Benin | 275.89 | 210.90 | 201.31 | 126.36 | 94.22 | 166.87 | 441.42 | 357.73 | 345.86 |
| Burkina Faso | -1.33 | -3.14 | -10.94 | -25.25 | -31.16 | -28.62 | -12.68 | 1.41 | 0.04 |
| Côte d'Ivoire | 128.88 | 109.46 | 83.77 | 52.33 | 37.26 | 47.49 | 64.03 | 68.20 | 62.33 |
| The Gambia | -57.06 | -58.54 | -62.16 | -68.22 | -70.63 | -69.08 | -62.05 | -56.37 | -57.16 |
| Ghana | 34.82 | 255.47 | 8.95 | -5.17 | -8.82 | 0.29 | 17.89 | 23.93 | 20.84 |
| Guinea | -20.25 | -21.65 | -28.66 | -39.72 | -44.58 | -38.51 | -28.27 | -27.53 | -29.11 |
| Guinea Bissau | -17.88 | -5.61 | -11.75 | -21.64 | -35.74 | -16.76 | -3.08 | 3.55 | 31.59 |
| Mali | 116.90 | 109.61 | 93.37 | 61.46 | 47.86 | 52.69 | 86.55 | 117.37 | 115.62 |
| Nigeria | -68.77 | -69.69 | -72.35 | -76.81 | -78.82 | -77.48 | -73.13 | -70.23 | -70.80 |
| Senegal | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Togo | -43.67 | -48.16 | -54.09 | -56.06 | -63.64 | -60.25 | -52.44 | -48.39 | -50.91 |

Source: Own composition

of the difference between RCP 8.5 and the BAU to the latter and are expressed as a percentage.

### Cotton simulation results under RCP 8.5 relative to the BAU

The patterns of cotton land use are also sensitive to a harsh climate change scenario (Table 6). Land use is expected to decline and to increase depending on the countries and the time periods, except in Côte d'Ivoire. Overall, the negative effects seem to be less frequent than the positive ones with the exception of Burkina Faso and Togo that may not experience any decrease in cotton land use. As of the exported quantities (Table 7), negative effects of a harsh climate change on cotton exports would be observed only in Benin in 2070, and in Mali from 2020 to 2060. Overall, cotton exports are positively affected by a harsh climate change, and there is a certain degree of fluctuation in the positive effects over years; the highest effects being observed at the end of the century for all countries except for Togo. These findings suggest that land productivity (cotton yield) could be higher under RCP 8.5 than under the BAU scenario in some countries, and these countries could take advantage of it to export more cotton. It appears that cotton exports are higher under RCP 8.5 than under RCP 4.5. These results underline the fact that distribution of rainfall under RCP 8.5 favours some ACZs within countries in terms of cotton production relative to RCP 4.5 (rendering them more suitable for cotton production). Such a positive effect of climate change on cotton yields is also found in the literature (Amouzou *et al.*, 2018; Gérardeaux *et al.*, 2013).

These countries are expected to be differently affected by a harsh climate change in terms of cashew nuts land use (Table 8). Cashew nuts land use could be low under RCP 8.5 compared with the BAU scenario in few countries regardless of the time periods (in The Gambia and Ghana). Moreover, cashew nuts land use is negatively affected by a harsh climate change in 2040 in Guinea Bissau and from 2040 to 2080 in Senegal. Two countries are expected to not experience in some extent any change in cashew nuts land use under RCP 8.5 (Guinea and Mali), while Burkina Faso and Togo would record no change in the land use under this climate scenario. The remaining West African countries could experience mostly or only increase in cashew nuts land use under RCP 8.5 relatively to the BAU scenario. As for exported quantities, a harsh climate change may be detrimental to cashew nuts exports in several countries (Table 9). Indeed, when compared to the BAU scenario, a contraction in cashew nuts exports is expected under RCP 8.5 in Burkina Faso, The Gambia, Guinea, Guinea Bissau, Nigeria and Togo. Nonetheless, Senegal may not experience any change in cashew nuts exports patterns, while Benin, Côte d'Ivoire, Ghana and Mali are expected to increase cashew nuts exports under a harsh climate change scenario relative to the BAU. It should be noted that the highest increase in percentage is expected from Benin. Overall, cashew nuts exported quantities are expected to be lower under a harsh climate change than under a moderate climate change.

The findings presented above show the disparities in the effects of climate change across climate scenarios, countries and crops. Sometimes the observations show that climate impacts may be less severe in equatorial regions than temperate regions, though accounting for water use, adaptation potential, and adaptation capability alters this conclusion (Reilly and Hohmann, 1993). These findings are in line with the fact that there is a spatial dimension to the effects of global climatic change on agricultural production and trade (Lokonon *et al.*, 2019; Reilly *et al.*, 1994). Notably, Dellink *et al.* (2017) point out that the production of all commodities of the economy, including those that are heavily traded internationally, could be affected by the adverse impacts of climate change, but this is not the case with cotton and cashew nuts in West African countries. In fact, West African countries would potentially experience positive as well as negative effects of climate change, although there are disparities across countries, climate scenarios and crops.

**Table 6:** Cotton land use under RCP 8.5 relative to the BAU scenario (%).

| | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|
| Benin | 3.00 | 22.12 | -15.95 | -14.18 | -12.71 | -52.35 | 17.72 | 0.00 | 146.87 |
| Burkina Faso | 51.05 | 47.38 | 36.39 | 26.05 | 14.04 | 0.00 | 0.00 | 0.00 | 0.00 |
| Côte d'Ivoire | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mali | -43.44 | -36.47 | -33.65 | -39.40 | -37.50 | -38.58 | 0.00 | -0.04 | 0.00 |
| Togo | 898.45 | 545.36 | 341.17 | 344.67 | 227.00 | 40.91 | 291.92 | 169.24 | 0.00 |

Source: Own composition

**Table 7:** Cotton exports under RCP 8.5 relative to the BAU scenario (%).

| | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|
| Benin | 39.70 | 77.42 | 24.74 | 36.00 | 51.03 | -3.03 | 212.08 | 188.32 | 788.79 |
| Burkina Faso | 74.15 | 80.98 | 72.53 | 69.93 | 70.46 | 82.93 | 131.24 | 179.29 | 196.29 |
| Côte d'Ivoire | 49.01 | 54.06 | 59.64 | 76.83 | 91.89 | 103.34 | 118.26 | 144.07 | 157.72 |
| Mali | -35.30 | -22.51 | -16.56 | -20.15 | -8.81 | 10.00 | 141.52 | 195.61 | 214.91 |
| Togo | 1,754.76 | 1,147.86 | 774.40 | 838.76 | 641.94 | 261.72 | 1,040.88 | 784.94 | 243.03 |

Source: Own composition

Actually, cotton is a $C_3$ crop, and so $CO_2$ fertilisation effects could sometimes compensate for yield loss resulting from climatic parameters, and even may reverse it (Amouzou *et al.*, 2018; Gérardeaux *et al.*, 2013). Nevertheless, cashew nuts are expected to be more negatively affected than cotton. Rupa *et al.* (2013) point out that as cashew nuts are grown in ecologically sensitive areas (e.g., areas with high rainfall and humidity), climate change may be detrimental to them. The major factors that adversely affect cashew yields and the quality of cashew nuts include unseasonal rains and heavy dew during the flowering and fruiting period (Rupa *et al.*, 2013).

## Comparison of the findings, with and without taking into account cotton intermediary market power

The simulation results presented above with cotton intermediary market power effects accounted for are compared with those where these imperfections have not been taken into consideration. This sheds light on the errors made when intermediary market power in cotton domestic markets is not modelled. Under RCP 4.5, it appears that the countries would experience a decline in cotton exports relative to the BAU in some years, except for Côte d'Ivoire, in whose case accounting for market power does not have any significant effect. Overall, not accounting for intermediary market power may lead one to over-estimate or under-estimate the effect of a moderate climate change on cotton exports, depending on the time periods. Not accounting for cotton market imperfections would have a slight effect on cashew nuts exports under a moderate climate change, except in Benin, where it underestimates the positive effect. The simulation results show that the non-inclusion of intermediary market power would lead to the under-estimation and the over-estimation of the effect of a harsh climate change on cotton production depending on the countries and the time periods. Furthermore, the positive effect of RCP 8.5 on cashew nuts exports is over-estimated by the non-inclusion of intermediary market power in cotton domestic market in Benin, Côte d'Ivoire and Mali. Nonetheless, the null effect under RCP 8.5 turns out negative overall in Burkina Faso and Togo. Consequently, it can be seen that ignoring cotton market imperfections in the modelling affect the simulation results.

**Table 8:** Cashew nuts land use under RCP 8.5 relative to the BAU scenario (%).

| | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|
| Benin | 59.15 | 35.99 | 30.88 | 25.89 | 34.51 | 75.61 | 114.57 | 108.90 | 92.77 |
| Burkina Faso | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Côte d'Ivoire | 31.79 | 22.06 | 15.10 | 10.24 | 7.25 | 4.79 | 3.18 | 2.11 | 0.00 |
| The Gambia | -96.70 | -95.81 | -94.48 | -92.70 | -91.32 | -89.97 | -86.77 | -82.69 | -77.80 |
| Ghana | -2.18 | -2.46 | -2.35 | -2.15 | -1.90 | -1.61 | -1.32 | -1.04 | -0.79 |
| Guinea | 0.96 | 0.40 | 0.26 | 0.18 | 0.12 | 0.08 | 0.05 | 0.00 | 0.00 |
| Guinea Bissau | 3.04 | 6.81 | -2.33 | 10.97 | 1.89 | 14.48 | 7.93 | 10.68 | 4.44 |
| Mali | 0.00 | 0.00 | 0.02 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 |
| Nigeria | 2.10 | 1.28 | 0.06 | 0.03 | 0.02 | 0.01 | 0.01 | 0.00 | 0.00 |
| Senegal | 1.67 | 0.38 | -0.06 | -0.04 | -0.03 | -0.02 | -0.01 | 0.00 | 0.00 |
| Togo | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Source: Own composition

**Table 9:** Cashew nuts exports under RCP 8.5 relative to the BAU scenario (%).

| | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|
| Benin | 256.53 | 198.24 | 154.77 | 104.56 | 103.78 | 200.06 | 358.36 | 382.49 | 301.10 |
| Burkina Faso | -3.65 | -6.35 | -15.82 | -29.08 | -35.48 | -29.76 | -12.36 | 2.10 | -2.24 |
| Côte d'Ivoire | 127.96 | 102.68 | 74.61 | 41.58 | 27.66 | 37.72 | 54.57 | 50.37 | 34.94 |
| The Gambia | -98.43 | -98.12 | -97.79 | -97.61 | -97.42 | -96.83 | -94.99 | -92.86 | -91.57 |
| Ghana | 31.77 | 26.81 | 14.90 | -2.58 | -8.19 | 2.12 | 17.73 | 16.46 | 6.25 |
| Guinea | -23.24 | -27.01 | -33.41 | -45.46 | -49.43 | -44.24 | -35.29 | -36.60 | -42.63 |
| Guinea Bissau | -19.33 | -12.13 | -20.72 | -32.21 | -42.04 | -13.20 | 4.77 | 11.36 | -3.56 |
| Mali | 107.84 | 102.03 | 82.07 | 53.10 | 38.54 | 49.96 | 86.79 | 119.18 | 112.12 |
| Nigeria | -69.90 | -71.14 | -74.21 | -78.55 | -80.37 | -78.50 | -73.98 | -71.95 | -73.91 |
| Senegal | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Togo | -50.24 | -51.78 | -56.89 | -63.86 | -66.15 | -62.07 | -53.75 | -51.62 | -56.62 |

Source: Own composition

### Sensitivity of exports to the reduction of intermediary market power in cotton domestic markets

A reduction in intermediary market power in cotton domestic markets is simulated. That is, two simulations are run assuming respective reductions of 25% and 50% in intermediary market power under the two climate scenarios, in order to investigate to what extent reducing market imperfections could mitigate the effects of climate change on the quantities of cotton exported. To shed light on the differences from the climate scenarios, the simulation results under the climate scenario coupled with the reduction of intermediary market power are presented relative to cotton exports under the corresponding climate scenario in percentages (ratio of the difference between the RCP coupled with the reduction in intermediary market power and the RCP to the RCP, expressed as percentages). The simulation results indicate that under the two climate scenarios, reductions in market imperfections could mitigate the negative effects of a moderate climate change or strengthen a country's ability to benefit from the opportunity arising from this climate change scenario in terms of increasing these exports, depending on the countries (Tables A3 & A4 of the Appendices). It is noteworthy that the 50% reduction in cotton market imperfections has to a certain extent different effects only under RCP 4.5 climate scenario, but the trend is similar to what is found with the 25% reduction (Table A5 of the Appendices). Such a reduction could have indirect effects on cashew nuts exports (Tables A6, A7 & A8 of the Appendices). Decreasing intermediary market power in cotton domestic markets could affect countries' capacity to increase cashew nuts production and exports in the presence of climatic change and could exacerbate the negative effect of climate change, depending on the country and the climate change scenario. It should further be noted that reducing market imperfections may not automatically lead to higher returns to farmers (Delpeuch, 2009). In fact, a perfectly competitive sector performs well in terms of cost efficiency and provides relatively high prices to farmers but performs badly in terms of quality, input provision, extension and yields. However, a public monopoly performs poorly in terms of ginning cost-efficiency but does well in terms of inputs provision, extension, yields and farmers' welfare (Delpeuch, 2009).

## Conclusion and policy implications

Given the importance of West African countries' integration with the world agricultural supply chain to the promotion of economic growth, development and poverty reduction, this paper has aimed to analyse the extent to which climate change affects cotton and cashew nuts production and exports in the West African countries using a regional bio-economic model, while also accounting for the presence of intermediary market power in cotton domestic markets. This paper has addressed three specific objectives. First, the paper has shown that the countries would be differently affected under RCP 4.5 and RCP 8.5 in terms of cotton and cashew nuts land use. The effects vary across countries, ranging from experiencing only a decline, or only an increase to experiencing both a decline and an increase in land use. Second, the paper has revealed that the effects of climate change on the quantities of cotton and cashew nuts exported are similar to those it has on land use, with the positive effects being more pronounced for cotton exports in particular. Third, the paper has found that a reduction in cotton market imperfections can either mitigate the negative effects of climate change or lessen a country's ability to take advantage of the opportunities arising from climate change in terms of increasing cotton exports, or strengthen this capacity, or have mixed effects depending on the countries. Therefore, actions need to be taken to mitigate the negative effects of climate change on cotton (especially in Mali) and cashew nuts (in Burkina Faso, The Gambia, Guinea, Guinea Bissau, Nigeria and Togo under conditions of moderate climate change) production and exports and also to take advantage of the beneficial effects involving these crops given climatic change. In the case of moderate climate change, the countries may only correct for cotton market imperfections, while under harsh climate change, they may combine this with an increase in cotton and cashew nuts land productivity. The main limitation of this paper is that cashew nuts market imperfections are not taken into account. Thus, future investigations could include intermediary market power in cashew nuts domestic markets in the regional bio-economic model in order to improve the precision of the model.

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# Appendix

**Appendix 1:** Cotton and cashew nuts yield functions' parameters (dependent variable: ln(yield)).

| Variables | Cotton | | Cashew | |
|---|---|---|---|---|
| | Coefficients | T-statistics | Coefficients | T-statistics |
| Temperature | -1.12* | -1.95 | -0.86 | -0.89 |
| Temperature² | 0.02* | 1.72 | 0.01 | 0.70 |
| Rainfall | -0.01*** | -3.14 | 6.60e-04 | 1.37 |
| Rainfall² | 1.68e-07 | 1.20 | -5.37e-07** | -2.11 |
| Temperature*Rainfall | 2.26e-04*** | 3.50 | | |
| Variance of temperature | 0.01 | 0.66 | 0.06 | 1.25 |
| Variance of rainfall | -6.95e-05** | -2.57 | 9.92e-05*** | 2.61 |
| Clay | -0.04 | -1.03 | -0.07 | -0.80 |
| Sandy | 0.03 | 0.60 | 0.01 | 0.07 |
| Constant | 14.96** | 2.14 | 11.69 | 1.04 |
| Observations | 297 | | 291 | |
| $R^2$ | 0.07 | | 0.08 | |

Note: *** p<0.01, ** p<0.05, * p<0.1. These estimations results are used to project crop yields for agro-climatic zones, soils and countries from 2020 to 2100. For crop yield projections, future climate data with respect to RCP 4.5 & RCP 8.5 are used and holding soil variables equal to their means.
Source: Own composition

**Appendix 2:** Selected parametric distributions used in the Monte Carlo simulations

| | GDP growth | | | Population Growth | | | Inflation rate | | |
|---|---|---|---|---|---|---|---|---|---|
| | Distrib. | Mean | Std. Dev. | Distrib. | Mean | Std. Dev. | Distrib. | Mean | Std. Dev. |
| Benin | Normal | 4.04 | 3.05 | Normal | 3.01 | 0.21 | Normal | 0.04 | 0.07 |
| Burkina Faso | Beta | 1.10 | 1.11 | Normal | 2.74 | 0.20 | Normal | 0.03 | 0.05 |
| Côte d'Ivoire | Normal | 1.00 | 3.39 | Normal | 3.05 | 0.86 | Normal | 0.04 | 0.05 |
| The Gambia | Normal | 3.70 | 2.91 | Normal | 3.42 | 0.59 | Normal | 0.09 | 0.10 |
| Ghana | Beta | 1.77 | 1.01 | Normal | 2.72 | 0.29 | Normal | 0.33 | 0.30 |
| Guinea | Normal | 3.67 | 1.67 | Normal | 2.85 | 1.28 | Normal | 0.19 | 0.14 |
| Guinea Bissau | Uniform | 0.98 | 5.42 | Normal | 2.17 | 0.24 | Normal | 0.02 | 0.04 |
| Mali | Normal | 3.98 | 5.39 | Normal | 2.49 | 0.61 | Normal | 0.03 | 0.07 |
| Niger | Normal | 2.06 | 5.23 | Normal | 3.36 | 0.35 | Normal | 0.03 | 0.09 |
| Nigeria | Normal | 3.17 | 5.89 | Normal | 2.57 | 0.80 | Normal | 0.21 | 0.18 |
| Senegal | Normal | 1.66 | 1.08 | Normal | 2.78 | 0.23 | Normal | 0.04 | 0.07 |
| Sierra Leone | Logistic | 5.03 | 3.43 | Normal | 3.12 | 1.08 | Normal | 0.09 | 0.09 |
| Togo | Normal | 2.55 | 6.10 | Normal | 2.90 | 0.38 | Normal | 0.05 | 0.09 |

Source: Own composition

**Appendix 3:** Sensitivity of cotton exports to 25% reduction of market power in cotton domestic markets under RCP 4.5 (%).

| | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|
| Benin | 5.71 | 7.40 | 9.06 | 0.02 | 0.40 | -9.55 | 0.33 | 0.00 | 0.00 |
| Burkina Faso | 6.49 | 6.84 | 4.08 | 4.69 | 5.30 | 4.92 | 3.59 | 2.54 | 1.77 |
| Côte d'Ivoire | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mali | 360.76 | 271.42 | 245.94 | 158.89 | 111.02 | 76.15 | 2.13 | 1.15 | 0.76 |
| Togo | 13.70 | -10.15 | 15.75 | -0.38 | 19.46 | 15.22 | 1.63 | 0.98 | 1.10 |

Source: Own composition

**Appendix** 4: Sensitivity of cotton exports to 25% reduction of market power in cotton domestic markets under RCP 8.5 (%).

| | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|
| Benin | -15.20 | -43.09 | -14.73 | -10.82 | -7.97 | 134.90 | -0.71 | 0.00 | -0.63 |
| Burkina Faso | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| Côte d'Ivoire | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mali | -40.76 | -39.11 | -35.64 | -35.08 | -30.04 | -22.81 | 0.00 | 0.03 | 0.00 |
| Togo | -0.47 | -0.41 | -0.38 | -0.38 | -0.29 | -0.15 | 0.61 | 0.00 | 0.00 |

Source: Own composition

**Appendix 5:** Sensitivity of cotton exports to 50% reduction of market power in cotton domestic markets under RCP 4.5 (%).

| | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|
| Benin | 5.71 | 7.40 | 9.06 | 0.02 | 0.41 | -9.58 | 0.33 | 0.00 | 0.00 |
| Burkina Faso | 6.49 | 6.84 | 4.08 | 4.69 | 5.30 | 4.92 | 3.59 | 2.54 | 1.77 |
| Côte d'Ivoire | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mali | 360.76 | 271.42 | 245.94 | 158.89 | 111.02 | 76.15 | 2.13 | 1.15 | 0.76 |
| Togo | 8.10 | -9.87 | 8.30 | 1.02 | 13.88 | 0.33 | 1.05 | 0.89 | 1.46 |

Source: Own composition

**Appendix 6:**: Sensitivity of cashew nuts exports to 25% reduction of market power in cotton domestic markets under RCP 4.5 (%).

| | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|
| Benin | -0.75 | 0.99 | -1.97 | -0.01 | -0.06 | -0.06 | -2.29 | -0.17 | 0.23 |
| Burkina Faso | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Côte d'Ivoire | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mali | 0.01 | 0.00 | -0.05 | -0.03 | -0.02 | -0.02 | 0.05 | 0.07 | 0.03 |
| Togo | -8.58 | 1.46 | 0.04 | -11.19 | 0.01 | 0.01 | -0.02 | 0.00 | 0.01 |

Source: Own composition

**Appendix 7:** Sensitivity of cashew nuts exports to 25% reduction of market power in cotton domestic markets under RCP 8.5 (%).

| | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|
| Benin | -0.53 | -3.99 | -6.07 | -2.20 | 3.75 | -0.35 | -0.44 | -4.47 | -0.06 |
| Burkina Faso | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Côte d'Ivoire | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mali | -0.46 | -0.31 | -0.24 | -0.16 | -0.11 | -0.07 | -0.05 | -0.03 | -0.02 |
| Togo | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Source: Own composition

**Appendix 8:** Sensitivity of cashew nuts exports to 50% reduction of market power in cotton domestic markets under RCP 4.5 (%).

| | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|
| Benin | -0.76 | 0.99 | -1.97 | -0.02 | -0.06 | -0.04 | -2.26 | 0.14 | 0.19 |
| Burkina Faso | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Côte d'Ivoire | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mali | 0.01 | 0.00 | -0.05 | -0.03 | -0.02 | -0.02 | 0.05 | 0.07 | 0.03 |
| Togo | -8.50 | -2.26 | 0.04 | -11.18 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 |

Source: Own composition