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Contents

List of Figures

List of Tables

Acronyms

AO	Additive outlier
ARIMA	Autoregressive Integrated Moving Average
CAGR	Compound Annual Growth Rate
CRP	CGIAR Research Program
DSSAT	Decision Support System for Agrotechnology Transfer
ETP	Eastern Tropical Pacific
FFC	Fine Flavour Cocoa
FTA	(CRP) Forests, Trees and Agroforestry
GCM	Global Circulation Models
GFSF	Global Futures & Strategic Foresight (initiative)
ICCO	International Cocoa and Coffee Organisation
IFPRI	International Food Policy Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
INTERCOM	Simulation model for INTERplant COMpetition
IPCC	the Intergovernmental Panel on Climate Change
IPM	Integrated pest management practices
IPR	Intrinsic productivity growth rates
LS	level shift
LSP	light saturation point
MA(P)E	Mean Absolute (Percentage) Error
MAXENT	maximum entropy
PIM	(CRP) Policies, Institutions, and Markets
PTP	Production Transformation Program
SCM	Simple Climate Models
SUCROS	Simple and Universal Crop growth Simulator
TC	transitory change

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Abstract

Cocoa is a food-industrial crop that could play a more important role in poverty reduction for small producers in developing countries worldwide. Every year, the cocoa-chocolate value chain moves billions of dollars, providing important dividends for producing countries and for national and international companies around the world.
The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) is a structural simulation model, which allows for future analysis of cocoa market globally. The model has been developed at International Food Policy Research Institute (IFPRI) to consider the long-term challenges facing policymakers in reducing hunger, and poverty in a sustainable fashion. IMPACT is the main quantitative tool used by the Global Futures & Strategic Foresight (GFSF) initiative, in which Bioversity International is involved as a partner.

The aim of this study is to validate the performance and improve parameterization of IMPACT cocoa components. The main objective is to review and suggest changes to the Intrinsic Productivity Growth Rates (IPRs) for cocoa in order to improve the model's baseline projections. It focuses on ten largest cocoa producing countries in reviewing parameters related to yield growth rates until 2050. Based on historical cocoa yield time series, as reported by FAO Stat, forecasts are made using an Autoregressive Integrated Moving Average (ARIMA). The forecast together with statistically estimated prediction intervals, supported by literature sources and expert knowledge are compared against respective yield trajectories embedded in IMPACT in order to make recommendations. For each country, we discuss the latest information about hindrances and opportunities to cocoa yield growth, including policies, planned investments and disease status.

In almost all the cases, except Indonesia, we recommend adjustments of the IPRs. Alarmingly, none of the countries is projected under baseline scenario assumptions to exceed average yield level of 1 t/ha and half of them is expected to remain below 0.6 t/ha until 2050. This emphasizes the need for a change of the business as usual policies and investments in order to improve the livelihoods of the cocoa growing farmers around the world.

1. Introduction

Cocoa (*Theobroma Cocoa*) is a food-industrial crop of significant importance that has still a role to play in poverty reduction of depressed regions of the humid tropics. Although cocoa is not a typical staple or food security crop, its production is largely in the hands of small producers in developing countries of Africa, Latin America, Asia and Oceania. Farmers that hold between 1 to 10 hectares cultivate more than 90% of the total cocoa produced in the world (Poelmans & Swinnen, 2016). It is estimated that about 5 to 6 million farmers from Africa, Asia, Latin America and Oceania produce cocoa. In fact, the natural habitat for growing cocoa trees is concentrated among the countries comprised in a belt between 10°N and 10°S of the Equator because of its need for appropriate climate factors, particularly warm temperatures, adequate rainfall, high moisture and specialist pollinators (ICCO, 2013).

Every year the cocoa-chocolate value chain moves billions of dollars providing important dividends for producing countries and for national and international companies around the world. In 2013, 4.6 million tons of cocoa beans were produced in more than 50 countries on approximately 10 million hectares for a total export value of US$ 15 billion (FAOStat, 2018). Cocoa thus is an industrial crop of great economic importance, but the economic benefits generated by this industry do not necessarily reach the cocoa producers. In fact, an average cocoa producer from the humid tropics is poor, middle aged, and holds a small plot of old cocoa trees. This farmer cannot secure his/her subsistence solely on cocoa production and (s)he has often a different primary or secondary source of income(Hütz-Adams *et al*., 2016).

Currently, the top ten producers of cocoa in the world are *Côte d'Ivoire*, Ghana, Cameroon and Nigeria in West Africa; Indonesia in South East Asia; and Ecuador, Brazil, Peru, the Dominican Republic and Colombia in Latin America (see Table 1). The two main producers have a considerably higher level of production than the rest of the countries. In spite of facing many challenges like poor soil fertility, poor infrastructure, relatively low quality of plant material and expensive inputs they will remain in this position for some time, particularly *Côte d'Ivoire*, accounting for the 33% of the global production (FAOStat, 2018). The rest of the producers, particularly the ones occupying the last three positions vary continuously, with Peru growing fast, Columbia and Dominican Republic fluctuating and Indonesia declining very fast.

The demand and consumption of chocolate are strongly concentrated in the United States and Europe, while among the main ten cocoa producers only Brazil is also in the top ten of consumers. With China, India, and Russia becoming important consumers of cacao products, the expansion of the demand in these countries and other emerging economies, has resulted in an increased concern from the industry about the future supply of cacao (Janssen & Riera, 2016; Li Fan & Di Mo, 2016).

Moreover, the dependability of the production on *Côte d'Ivoire* and Ghana had been an additional source of concern for the actors of the cacao-chocolate value chain. This has translated in a growing direct support of the industry to cacao production and cacao research in collaboration with local institutions. Research that can benefit directly cacao producers is however still needed.

Table 1 Global cocoa production information for 2016

Country	Production (tons)	% of global production	Area harvested (ha)	% of global area
Côte d'Ivoire	1,472,313	33.0%	2,851,084	27.9%
Ghana	858,720	19.2%	1,683,765	16.5%
Indonesia	656,817	14.7%	1,701,351	16.6%
Cameroon	291,512	6.5%	723,853	7.1%
Nigeria	236,521	5.3%	838,046	8.2%
Brazil	213,843	4.7%	720,053	7.0%
Ecuador	177,551	3.9%	454,257	4.4%
Peru	107,922	2.4%	125,580	1.2%
Dominican Republic	81,246	1.8%	172,940	1.7%
Colombia	56,163	1.2%	165,844	1.6%

Source: FAOStat (2018)

Due to high economic significance of cocoa and its impact on livelihoods of millions of farmers, it is important to understand and quantify threats and opportunities for future cocoa demand and supply and its role in the global food system.

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) is an example of a structural simulation model, which allows for future analysis of cocoa market globally. The model has been developed at International Food Policy Research Institute (IFPRI) to consider the long-term challenges facing policymakers in reducing hunger, and poverty in a sustainable fashion. IMPACT is the main quantitative tool used by the Global Futures & Strategic Foresight (GFSF) initiative, in which Bioversity International is involved as a partner.

Currently, IMPACT is a network of linked economic, water, and crop models (for selected crops). At its core is a partial equilibrium dynamic multi-market economic model, which simulates national and international agricultural markets in the long-term time horizon to 2050. It distinguishes 62 commodity markets and 320 Food Production Units (FPUs), which are sub-national geospatial units that are generated by the intersection of 159 countries with 154 hydrological basins (Robinson *et al.*, 2015).

IMPACT is a partial equilibrium and structural model that simulates the operation of national and international markets, solving for production, consumption and prices that equate local demand and supply with global /international trade (net trade equal to zero). It is a partial equilibrium model in the sense that it considers only agricultural commodities and does not provide feedback to the general economy, for example to labour markets. It is a structural model because it represents behaviour of economic agents that determine supply and demand for agricultural commodities in agricultural markets.

Crop production in IMPACT is a product of both, area and yield response functions. Crop yields are a function of commodity prices, prices of inputs, available water, climate, and exogenous trend factors. The exogenous trend factors are represented by intrinsic productivity growth rates (IPR). This exogenous component of yield encompasses long-term improvements in yield, continuing "trends observed during the past 50 to 60 years in an informed extrapolation" (Robinson *et al*., 2015; p.13). Thus, it represents a non-price component in the 'baseline' or 'business as usual' scenario of yield growth. The final yield is a combination of IPR, water and climate shock responses, and price change responses.

Cocoa is a new crop that has recently been separately added to IMPACT. In an earlier version of the IMPACT model was aggregated as "other crops". In the current version, demand, production and trade of cocoa are disaggregated. The details about productivity and demand changes still need to be adjusted. This is the effort of the institutions involved in the GFSF, in particular Bioversity International aims at improving the representation of cocoa in IMPACT by reviewing and suggesting adjustments to the model's key parameters (Robinson *et al.*, 2015).

In IMPACT, cocoa responses to climate change (i.e. to the effect of changes in temperature and precipitation) are calculated based on averages from other, biophysically similar crops (C3 crop group), which are well represented with a crop model suite, DSSAT (Robinson *et al.*, 2015). This is not ideal and IMPACT developers are looking for best alternatives to estimate the effect of climate change on this crop.

Since IPRs constitute such an important component of the final yields, combining their exogenous elements, and consequently affecting production, which further impacts prices, trade and consumption, it is necessary to ensure that they incorporate the most recent knowledge about the future. The objective of this study is to review and suggest changes to the IPRs for cocoa in order to improve the model's baseline projections. Since we cannot directly estimate IPRs, we forecast possible future yields and propose changes in existing IPRs. For this purpose, we focus on analysing future yield growth trends for the ten largest producing countries, which jointly produce more than 90% of the world's total cocoa (table 1). With such high volumes of production, these countries determine global price equilibrium, whereas smaller producers are considered to be "price-takers".

The literature using cacao production models cites mainly studies using regression or conceptual models (Zuidema *et al*., 2005). These models have limited applicability to a wide range of locations or are not appropriate for yield simulations. Biophysical models can overcome these limitations. For example, a growth and production model for cacao developed by Zuidema *et al*. (2005), SUCROS-Cacao, is based on the SUCROS and INTERCOM physiological crop growth models (Kropff & van Laar, 1993; van Ittersum et al., 2003; van Laar, Goudriaan, & van Keulen, 1992, 1997).

SUCROS-Cacao calculates light interception, photosynthesis, maintenance respiration, evapotranspiration, biomass production and bean yield for cacao trees grown under shade trees. The model uses about 85 morphological and physiological parameters of cacao trees detailed in Zuidema *et al*. (2003). The model also uses weather and soil data and information on the cropping system.

Climate and soil[1] greatly influence cacao production. In producing countries, the pattern of cropping cacao is related to rainfall distribution (Anim-Kwapong & Frimpong, 2004). Worldwide, large cacao plantations are in regions where the mean temperature ranges from 22-25°C (Läderac*h et al*., 2011). Solar radiation is also critical for this crop and it is often cultivated under shade[2]. Anim-Kwapong and Frimpong (2004) report that while prolonged exposure to high light intensities damages the photosynthetic mechanism of the leaves, low light intensities suppress flower production, having a considerable depressing effect on production (Asomaning *et al*., 1971). A change in rain or temperature would likely alter the geographical distribution of host and pathogen/pests, affect crop yields, and have an impact on farm income. This information is critical in evaluating the impact of climate change.

The literature evaluating the impact of climate change on cacao cultivation is not large and few studies have used climatic simulation models. The studies concentrate mainly in the African region particularly *Côte d'Ivoire* and Ghana due to their significant economic importance. Anim-Kwapong and Frimpong (2004) carried out an evaluation of the impact of climate change on cacao production in Ghana, using a 30-year period climatic data and General Circulation Models in conjunction with Simple Climate Models (SCM). The General Circulation Model predicted

[1] "The best soils for cacao production tend to have an average pH 5.6-7.2 in 1:2.5 water: soil, C/N ratio between 10-12, organic carbon not less than 3%, base exchange capacity of 3-15 me/100g soil available P greater than 20ppm in the 0-5 cm and 15 ppm in 0-20 cm layer, exchangeable K not less than 0.25 /100g soil, (Ca + Mg) about 8-13 me/100g soil and no aluminum in the exchange complex (Ahenkorah, Halm, Appiah, & Akrofi, 1982)." (Anim-Kwapong & Frimpong, 2004).

[2] "Cacao has a low light saturation point (LSP) of 400 µ E m-2 s-1 and a low maximum photosynthetic rate (7mg dm-1 h-1) at light saturation (Hutcheon, 1981). The photosynthetic rate of the crop decreases if the photosynthetic apparatus is exposed to light intensities exceeding 60% of full sunlight that is 1800 µ mol m-2 s-1 (Galyuon, McDavid, Lopez, & Spence, 1996)." (Anim-Kwapong & Frimpong, 2004).

progressive rise in temperatures and reduction in rainfall in the cacao producing forest belt of Ghana from 2020 to 2080. Multiple regression analysis showed that over 60% of the variation in the production of cacao beans was explained by the combination of the preceding year's total annual rainfall, total rainfall in the two driest months and total sunshine duration. Therefore, a consistent decrease in output from 2020 to 2080 could be expected.

The International Center for Tropical Agriculture (CIAT) conducted an evaluation (Läderach et al., 2011; Läderach, Martinez-Valle, Schroth, & Castro, 2013) for Ghana and *Côte d'Ivoire* based on the combination of current climate data and climate data generated using WorldClim (www.worldclim.org). To develop predictions of future climate the authors used 19 of the 21 Global Circulation Models (GCM) estimated by the Intergovernmental Panel on Climate Change (IPCC) – Fourth Assessment Report (IPCC, 2007) and downscale the data to adjust to a lower resolution using a delta method. The model was expanded (Läderach et al., 2013) to reflect changes in evapotranspiration due to higher temperatures and lower precipitation, which could be particularly critical in the producing areas in Ghana and *Côte d'Ivoire*. To evaluate the suitability of current cacao-growing areas to continue growing this crop by 2030 and 2050, the researchers used maximum entropy (MAXENT) method - a general-purpose method for making predictions or inferences from incomplete information. Thus, climatic suitability for cacao here refers to the probability that cacao grows well, judged using favourable climatic variables. The study concluded that under the A2 scenario (business as usual) climate change could present not only threats but also opportunities. The MAXENT model predicts an overall decrease in the climatic suitability of the current growing regions due to higher evapotranspiration. Since a temperature increase of 3°C implies could rise Eastern Tropical Pacific (ETP) by 17% (Martin *et al.*, 1989; Rosenberg *et al.*, 1989), the model also shows that effect of increased ETP on cacao is strongest in the drier margins (the transition zone to the savanna), and lower in areas with a very wet climate (i.e. southwest corner of *Côte d'Ivoire*). The author also pointed out that changes in climatic suitability are predicted to occur over a time period of almost 40 years, which gives farmers time for adapting agronomic management or switching to other crops.

2. Methodology

As discussed above, the aim of this analysis is to validate the performance and improve parametrization of the cocoa component related to the ten largest cocoa producing countries in the IMPACT model. Specifically, the method consists of forecasting yield trends up to 2050, comparing this with the baseline yield trend projections in IMPACT and accordingly making recommendations regarding the IPRs.

Because of the complex nature of the processes affecting yields and high uncertainty around them until 2050, it is extremely difficult to make future yield forecasts. There are many factors outside of the biophysical sphere, for example industry participation across the value chain or access to capital for smallholders, which will strongly influence cacao yield developments in the future. Even adverse climate change impacts can be potentially mitigated through investments in new varieties, increased inputs or relocation of plantations. These factors make long-term crop model or maximum entropy forecasts 'incomplete', even though these are very good methods to answer specific questions, for example isolating impact of a particular factor on a particular variety. Additionally, lack of adequate data makes it very difficult to establish causality and control for all the important factors influencing yield developments. As a result, we use univariate time series model in order to predict general trend developments. We base our analysis on Autoregressive Integrated Moving Average (ARIMA).

In general, ARIMA models are used for forecasting variables using past values, that are very convenient in cases of lack of well-developed theory or limited information. ARIMA models have been widely used for forecasting agricultural production (Badmus & Ariyo, 2011; Sahu, Mishra, Dhekale, K.P., & Padmanaban, 2015).

It is an example of a univariate time series models based on just a few parameters and compact specification. This method allows us to make forecasts assuming that the yields will follow the previous trajectory, which is close to 'business as usual' scenario assumptions. In this way, we do not make any explicit assumption, for example about climate change and possible adaptation strategies. However, we assume that the net impact of all these factors on yield will follow the previous trajectory. Furthermore, cocoa is a perennial plant with a long production cycle (up to 30 years), which makes future yields strongly linked to their current and past levels through the condition and the age of the trees. This is a natural example of ARIMA-type process. Another advantage of this method is that we can produce methodologically consistent and comparable forecasts for all 10 countries without facing problems of incomplete and very different data availabilities for each country.

The major risk of relying on the past yield trajectories while projecting "business as usual" scenario is that "business as usual" might not be possible in many countries anymore due to rapid climate change and soil degradation combined with the lack of new land available for cocoa production. "Farming on existing land will become more challenging as soil fertility management is neglected (both soil health and availability of nutrients). Yield on existing farms will decline and replanting will become more and more difficult whilst young farms on old land without soil management will not yield well. What is new is that historically farmers would abandon old cocoa farms and cultivate a new farm (often by cutting down forest) and use up the 'forest rent'. This is not possible any more as forest land is less and less available" (van Grinsven, 2018).

Another risk factor which has to be considered, is that data quality and collection methods are often different across the countries. For example, FAOStat production volume data sometimes differs significantly from International Cocoa Organization (ICCO, 2018). The largest difference is in case of Indonesia, with ICCO reporting approximately only half of the FAO Stat values; while Ecuador is reported around 30% higher in ICCO data (in year 2016). As a result, the yields, which are calculated at FAO based on area and production volume, should be treated only as a proxy of the average yields. Furthermore, as a result of this method, yield values experience spikes related purely to the accounting method: for example, undervalued production area because of unreported/illegal cocoa plantations in forests result in yield overestimation, unreported/illegal imports or exports result in over- or under-estimation of yield respectively (van Grinsven, 2018). These spikes should be detected by the ARIMA model as outliers – noise, and separated from the trend information.

In its general form, an ARIMA model is characterized by three parameters *p, d* and *q*, ARIMA (*p,d,q*), where p is the order of autoregressive term, d is the degree of integration, and q is the order of moving average term. The model can be denoted as follows:

$$\Delta^d y_t = \mu + \gamma_1 \Delta^d y_{t-1} + \gamma_2 \Delta^d y_{t-2} + \cdots + \gamma_p \Delta^d y_{t-p} + \epsilon_t - \theta_1 \epsilon_{t-1} - \cdots - \theta_q \epsilon_{t-q}, \qquad (1)$$

where

$$\Delta y_t = y_t - y_{t-1} = (1-L) y_t,$$

and

$$\Delta^d y_t = (1-L)^d y_t.$$

In the notation above, L is a lag operator.

If y_t is a stationary series, which means that it has no trend, its variations around its mean have a constant amplitude, and it varies in a consistent manner, then $d = 0$. Otherwise, y_t is differentiated until $\Delta^d y_t$ becomes stationary. A stationary random variable can be regarded as a combination of signal and noise, where signal could be some sort of pattern. ARIMA provides a technique of separating signal from the noise, and extrapolating signals to obtain future forecasts. In the general form, presented in equation 1, future values of the series y_t are a combination of a constant, a weighted sum of the past values of y_t, and a weighted sum of the past errors, often called disturbances, or innovations. Depending how big p and q are, we can tell if the process has a long or a short "memory". The magnitude and the signs of the parameters γ and θ informs about the direction and the strength of the influence of the past values. In the basic example of ARIMA (1,0,0) with a constant, $\gamma_1$close to zero means that the values of y are close to its mean, μ, and $\gamma_1$close to one (must be less than one if y_t is stationary) means that deviations from the mean are large ($\gamma_1$times the previous value of y). Also, if γ_1 has a negative sign, the values of y_t will be oscillating around μ with small or large deviations from it, depending on the magnitude of γ_1.

In our analysis, we follow methodology described in (Petsakos *et al.*, 2016), which consists of the following steps:

1. Outliers are detected, with additive outlier (AO – spikes that do not affect the following values in the time series), transitory change (TC – effects that gradually disappear with time) and level shift (LS – a sudden permanent change in the level);
2. Taking into account the selected outliers, an optimal ARIMA model based on the information criteria and residual properties is selected;
3. In- and out-of-sample forecasts, together with 95% confidence intervals are generated based on the selected model and compared against the IMPACT baseline trajectory.

The details of the ARIMA model and estimation of the parameters and outlier effects can be found in (Pets*akos et al*., 2016), or in the original methodological paper (Chen & Liu, 1993). All calculations were done in the R package. A full summary of the estimated models and the outliers for each country is given in the appendix B.

The data used comes from FAOSTAT and covers years 1961-2014, since IMPACT has been also built with FAOSTAT data. The data was split into a 'training' sub-sample (1961-2012) used for estimation of the models, and a 'test' sub-sample for short-term in-sample evaluation of the ARIMA forecasts. IMPACT uses 2005 as a reference year, so we examine the model's projections for the period 2005-2014 along with the out-of-sample (2014-2050) ARIMA forecasts. On the graphs, these are compared with the projection from the IMPACT model (green line). Additionally, we provide quantitative evaluation of forecast accuracy in the form of in-sample forecast errors - MAPE and MAE, for both ARIMA and IMPACT forecasts. MAPE is a Mean Absolute Percentage Error, calculated as follows:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{y_t - \widehat{y_t}}{y_t}\right|$$

MAE stands for Mean Absolute Error, given by:

$$MAE = \frac{\sum_{t=1}^{n}|y_t - \widehat{y_t}|}{n}$$

MAE is a natural measure of average error magnitude and MAPE is a useful measure to compare forecasting precision in relative terms and allows for example comparing forecasts between different countries.

Finally, we compare out-of-sample forecasts using Compound Annual Growth Rate (CAGR), which measures average annual growth rate of yield:

$$CAGR = \left(\widehat{y_T} - \widehat{y_{t_0}}\right)^{\frac{1}{T-t_0}} - 1,$$

where $T = 2050$ and $t_0 = 2012$.

3. Cocoa yield forecasts for 2050

Considering the high economic importance that the cocoa-chocolate value chain represents globally and a steadily growing demand, it is therefore surprising that the yield performance of this crop had not witnessed any dramatic increase, as revealed by Figure 1. The average productivity of cocoa is only 30% higher than it was 50 years ago (FAOStat, 2018). This increment is considerably low compared to annual crops like wheat, maize, rice or soybean, that in the same period of time more than double their productivity (Fischer *et al*., 2014). While it is difficult to compare yield gains of cocoa with those of food security crops particularly targeted during the Green Revolution, it is still hard to understand why the world's average yield of this crop is just slightly above 0.4 t/ha, well below the 3-5 t/ha obtained under experimental conditions (Motamayor *et al*., 2008). Some of the main cocoa producing countries like Indonesia, Nigeria, Ecuador and Brazil are even behind the world's average (figure 1).

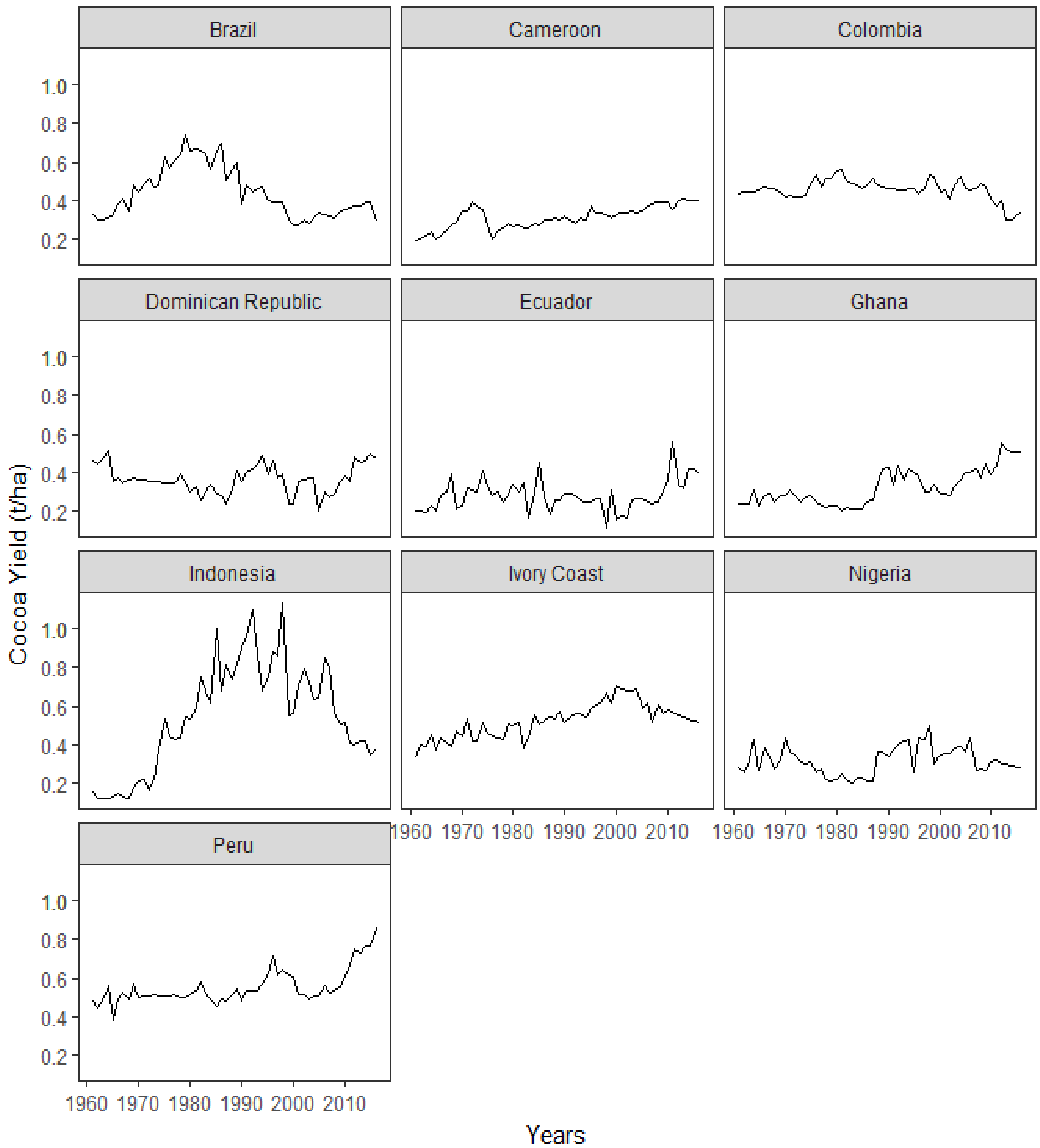

Figure 1: Cocoa Yields (t/ha) in the world's largest producing countries (1961 - 2016)
Source: Own design based on FAOStat (2018)

The need to enhance productivity is critical across regions. A number of agronomic, political, economic and environmental factors threatens the sustainability of the production. Factors that discourage long-term commitment of smallholders to grow the crop include: pest and disease infestations, use of poor quality seed and limited access to propagation materials (Laliberté & End, 2015), land degradation, environmental issues (Rice & Greenberg, 2000), the depletion of the "forest rent"(Fold & Neilson, 2016), social pressures to grow other crops, limited access to credit and services, economic issues (Swisscontact, 2016).

A growing demand for cocoa in emerging economies is pressing for either expansion of the cultivated area or better performance of the crop. Since the expansion of the agricultural frontier is reaching a limit, the improvement of yield performance is critical. Small households are unable to subsist on this crop only, despite record prices of cocoa beans on international markets. The industry concerned about the continuous supply of cocoa has been supporting in the implementation of projects to improve not only agricultural production but also the living conditions of the farmers and their families. Finally, climate change is a growing concern in crop production in general and cacao production in particular.

3.1 Côte d'Ivoire

Côte d'Ivoire is the world's largest producer of cocoa and with a total annual production of 1,472 thousand tons currently supplies more than 33 percent of the world's total cocoa (FAOStat, 2018). The cocoa sector is crucial for the *Côte d'Ivoire* economy, being responsible for over two-thirds of trade revenues from agriculture and around 40% of total revenues (FAOStat, 2018; WTO, 2018). Moreover, the importance of cocoa in *Côte d'Ivoire* is not only limited to being a strategic source of foreign exchange revenue but it is also a cash crop grown by around 600,000 to 900,000 smallholders (Fobelets & de Groot Ruiz, 2016; Smith Dumont *et al.*, 2014). Although cocoa is not a native crop of West Africa, *Côte d'Ivoire* leads cocoa production by a significant volume mainly due to the large area harvested and it is by far the leading country with more than 2.8 million ha dedicated to cocoa cultivation (FAOStat, 2018). However, productivity is rather low, where pests and diseases, among other factors limit productivity. Data reveals that yield has remained between 0.5 – 0.6 t/ha during the last 20 years, with a slightly decreasing trend since 2010 (FAOStat, 2018). The time series analysis for *Côte d'Ivoire* shows three different outliers: one additive outlier in 1971, one transitory change in 1982 and one level shift in 2005. While the transitory change in 1982 is attributable to the El Nino years 1982/83, characterized by drought and fires that severely affected cocoa plantations (Ruf *et al.*, 2015), the 2005 level shift is probably related to a decrease in farm-gate prices that could have encouraged farmers to shift investments towards other crops such as rubber and palm oil (Hatløy, Tewodros, Adeba, & Core, 2012). Nonetheless, the presence of some last micro-conflicts across the cocoa belt in correspondence with the end of the civil war could have affected negatively the productivity between 2004 and 2005 (Carroll, 2004).

The ARIMA model selected for *Côte d'Ivoire* is an ARIMA(4,1,0) with a drift:

$$\Delta y_t = 0.0067 - 0.8475\Delta y_{t-1} - 0.6541\Delta y_{t-2} - 0.5293\Delta y_{t-3} - 0.3957\Delta y_{t-4} + 0.0944AO_{1971} - 0.0897TC_{1982} - 0.1339LS_{2005} + \epsilon_t$$

IMPACT does not capture the level shift that occurred in 2005, hence IPRs should be adjusted downwards in order to adapt the prediction to the recent trend. Furthermore, the IMPACT forecast for 2012-2014 gave a high error (table 2). However, some reports suggest that that *Côte d'Ivoire* farmers have been strongly attracted by higher prices granted by the Ghanaian government, which resulted in cocoa smuggling from *Côte d'Ivoire* to Ghana in the last years (van Grinsven, 2018). As a result, Ivorian production would be underreported, leading to a lower calculated (total production divided by total area) yield. This hypothesis is supported by a positive shift in yields in Ghana in the same period (details in section 3.2). Consequently, we suggest treating this downward shift in yield as an outlier.

Table 2 Results summary for cocoa yield forecasts in Côte d'Ivoire

In sample (2012-2014)	**MAPE**	**MAE**
ARIMA	10.7	0.06
IMPACT	31.6	0.17
Out of sample	**CAGR**	**2050 yield (t/ha)**
ARIMA	1.02%	0.84
IMPACT	0.99%	1.00

Source: Own calculation

The key role *Côte d'Ivoire* plays in the cocoa value chain is recently raising concern regarding the capacity of the country of being able to supply global growing demand in the future. Similarly to other cocoa producing countries in West Africa, the expansions of the "cocoa frontier" and the establishment of new farmland and plantations in *Côte d'Ivoire* have strongly impacted tropical forests and protected areas (Ruf *et al.*, 2015). The growing global attention to environmental issues have led to actions by the *Côte d'Ivoire* government and international chocolate companies aiming to halt illegal cultivation and deforestation. As a result, in order to sustain the current production volume, yield levels need to increase. The major constraints identified, especially in remote areas, are from poor farming practices, and low access to credit, inputs and planting material. Further constraints to productivity are from ageing of trees and farmers and debilitating pests and diseases (Wessel & Quist-Wessel, 2015). International chocolate companies operating in the country, have been taking actions to alleviate some of these issues with investment in inputs and providing trainings to the farmers (Fobelets & de Groot Ruiz, 2016). Unless the necessary steps are taken, *Côte d'Ivoire* will unlikely maintain its primary role as cocoa producer by 2050. Currently, the country does not have enough planting material to guarantee its cocoa plantations' renovation or adequate infrastructure to link production to markets. Farmers, despite low profitability are likely to continue cocoa production because they rarely have alternative income generating activities to cocoa. Consequently, in the future we can expect relatively stagnant average yield with a high divergence of performances between different farmers (van Grinsven, 2018).

Both the IMPACT and ARIMA forecasts follow a growing trajectory towards 2050, however the IMPACT values are between 0.1 t/ha and 0.2 t/ha above the ARIMA generated numbers, which can be mostly attributed to the level shift in 2005. CAGR is similar for both forecasts, however the yield in 2050 differs due to different starting points. We suggest adjusting the IPRs downwards to match the actual yields within the training sample and leaving the IPRs unchanged for out of sample forecasts.

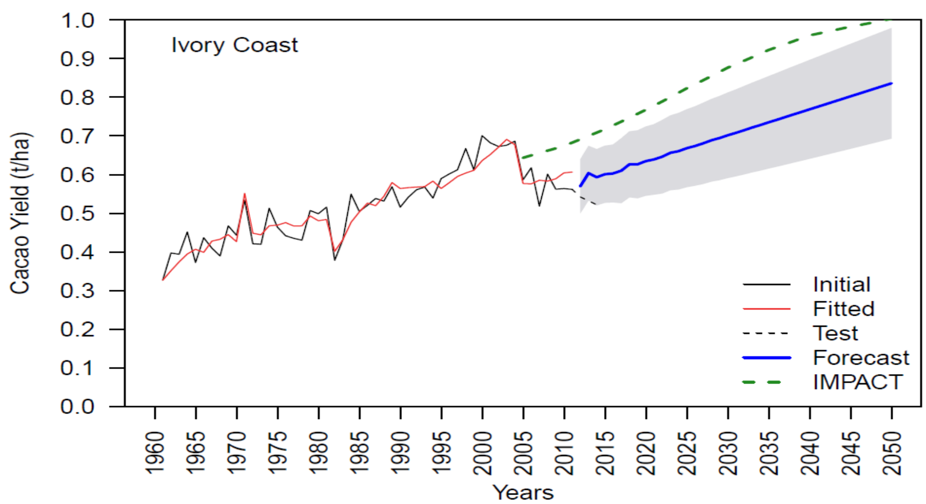

Figure 2 Cocoa yield forecast for Côte d'Ivoire
Source: Own calculation

3.2 Ghana

Ghana is the second most important cocoa producer in the world. Together with *Côte d'Ivoire* in 2016 it produced around 52% of the world's total. About 700,000 small-scale farms supply three quarters of the total cocoa produced in Ghana (Vellema, *et al.*, 2016). Currently, cocoa production takes place in seven regions, namely Ashanti, Brong Ahafo, Eastern, Volta, Central and Western North and Western South regions (COCOBOD, 2018). The role of cocoa production is fundamental in Ghana: it is the first agricultural exports commodity, an important cash crop, a source of foreign exchange, and tax revenues. (Aneani *et al.*, 2017)

Cocoa production has steadily risen, more than doubling in the last twenty years from 403,000 tons in 1996 to 858,720 in 2016 (FAOStat, 2018). COCOBOD, the government-owned cocoa marketing board, and its supporting measures to production are considered the main factors of this positive trend (Asante-Poku & Angelucci, 2013). In addition, the harvested area has increased, with around 1.6 million of ha dedicated to cocoa production. Despite the recent increasing trend, cocoa yields are still well below the potential as Ghana shares with *Côte d'Ivoire* similar limitations to production. The average cocoa farm is small, 2 ha or less, while the majority of farmers are aging (>50 years old) and so are their cocoa trees (Wessel & Quist-Wessel, 2015). According to Laven and Boomsma (2012), yield performances vary significantly across different farms and producers: between 50% and 65% of cocoa farmers produce around 0.4 t/ha, between 20% and 40% about 0.65 t/ha, while only a small remaining part can rely on high technology and achieve an average of 1.4 t/ha.

The statistical analysis detected one outlier - a level shift upwards in 1988, which is possibly related to a positive impact of series of reforms introduced by the Economic Recovery Program, launched in 1984. The reforms included Cocoa Rehabilitation Project (CRP) to gradually improve and stimulate the recovery of the cacao sector.

The intervention model selected for Ghana is an ARIMA(2,0,0) with a constant:

$$y_t = 0.2509 + 0.3288y_{t-1} + 0.3357y_{t-2} + 0.1243LS_{1988} + \epsilon_t$$

As can be seen from Figure 3, cocoa yields in Ghana show an upward trajectory in the last fifteen years, moving from 0.29 tons per ha in 2000 to 0.51 in 2016. However, both IMPACT and ARIMA do not detect the higher level of yields registered since 2012. Also, forecast errors for both models for 2012-14 give very high errors (table 3).

Table 3 Results summary for cocoa yield forecasts in Ghana

In sample (2012-2014)	**MAPE**	**MAE**
ARIMA	24.0	0.13
IMPACT	22.0	0.12
Out of sample (2015-2050)	**CAGR**	**2050 yield (t/ha)**
ARIMA	-0.18%	0.38
IMPACT	0.59%	0.51

Source: Own calculation

Yield growth beginning in the early 2000s was mainly due to a series of COCOBOD's measures such as the "Cocoa High-Tech" program, launched in 2002/2003, which entailed the provision of fertilizers to cocoa producers to increase outputs (Kolavalli & Vigneri, 2011) and the National Cocoa Rehabilitation Programme, implemented in 2011. The latter Programme has the major objective of improving the productivity and supporting the sustainability of cocoa plantations nationwide in the short and medium term, through rehabilitation and replacement of old plantations with improved hybrid varieties (Aneani *et al.*, 2017). Seedling production has been intensely extended with 50 million hybrid cocoa seedlings provided for free to the farmers in 2015 and 60 million in 2016 (Government of Ghana, n.d.). This positive trend could then result in a new level shift upwards. IPRs should be consequently adjusted bearing in mind that experts estimate potential yields equal to about double of the current yield (Sostizzo, 2017). However, as discussed in section 3.1, the high yield values reported in the last years could be inflated by smuggled cocoa from *Côte d'Ivoire* to Ghana. Consequently, part of the shift in yield performance in Ghana, recorded since 2012, can be possibly attributed to this phenomenon, as it would lead to higher reported production and eventually higher calculated yield. As a result, we suggest adjusting IPRs to match the in-sample observed yield values and for out of sample period lowering IPRs in order to reach the yield levels slightly above currently forecasted in IMPACT (figure 3).

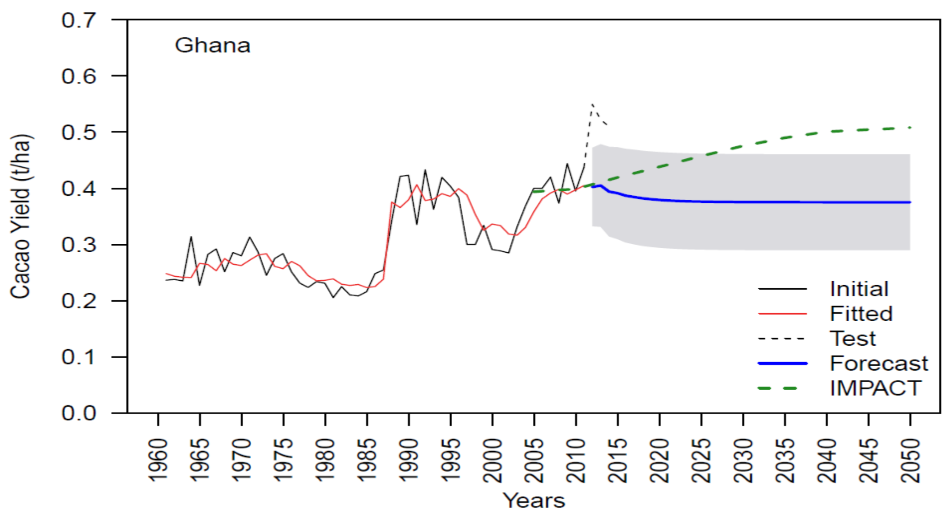

Figure 3 Cocoa yield forecast for Ghana
Source: Own calculation

3.3 Indonesia

Despite particularly low cocoa before 1980s, Indonesia is now the largest producing country in Asia and the third in the world. According to FAOStat (2018), this country produced 656,817 tons in 2016. However, as discussed above, there is a major discrepancy between data reported by FAO and ICCO (FAOStat, 2018; ICCO, 2018). As a result, there is high uncertainty about the precision of the reported numbers. Sulawesi, where around two thirds of the production take place, is the main Indonesian region for cocoa cultivation, followed by Sumatra (25%), Java (5%), Moluccas and

Papua (5%), Bali (3%) and Kalimantan (1%) (Directorate General of Estate Crops, 2015). Like in *Côte d'Ivoire* and Ghana, most of Indonesia's cocoa production comes from smallholder farmers, who are responsible for around 95% of the total (Witjaksono, 2016).

In 2010, Indonesian government introduced an export tax of 10% on cocoa beans in order to stimulate domestic processing capacity, which has increased significantly since then. According to ICCO, in 2018 Indonesian industries will grind 476,000 tons of cocoa beans. As a result, internal cocoa demand has increased and since 2014, Indonesia has turned into a net importer of cocoa beans. However, cocoa is still important for Indonesia as a source of foreign exchange earnings, but with the largest part often exported in the form of cocoa butter (FAOStat, 2018).

The upward trend in production reversed at the end of the 1990s in order to then grow again until exceeding production in Ghana to become, between 2005 and 2011, the second world's biggest cocoa producer (FAOStat, 2018). However, production has recently registered a sharp decrease, mainly caused by the fast spread of Cocoa Pod Borer (*Conopomorpha Cramerella*). The aging of the trees, planted in the 1980s, and farmers' limited cocoa management, knowledge, especially in terms of pest and disease control and soil management, are also limiting productivity and production (Fahmid, Harun, Fahmid, Saadah, & Busthanul, 2018; Tothmihaly & Ingram, 2017). In 2016, Indonesia has registered a level of yield of 0.39 tons per ha, lower than the world's average. This result is even more surprising if considering that only ten years ago, in 2006, the yield per ha was equal to 0.85 t (FAOStat, 2018). Recent government measures to boost production are not having the expected results and new interventions need to be implemented to revitalize cocoa sector. It has also to be considered that differently from *Côte d'Ivoire* and Ghana, Indonesian farmers have good opportunities to shift production to other crops if more profitable, such as palm oil or rubber (van Grinsven, 2018). Statistical analysis shows two additive outliers in 1985 and in 1998. The selected model is an ARIMA (2,1,0):

$$\Delta y_t = 0.2669\Delta y_{t-1} - 0.4846\Delta y_{t-2} + 0.4043AO_{1985} + 0.4403AO_{1998} + \epsilon_t$$

IMPACT has not captured the recent level shift downwards occurred in 2010. Also, forecast errors from IMPACT are large (table 4), whereas ARIMA produced an accurate in sample forecast for 2012-14. Consequently, IPRs should be adjusted downwards for both of these periods. Out of sample forecast in IMPACT is within the 95% ARIMA forecast interval, however it is systematically above the ARIMA mean forecast. Considering the potential for successful farmers to reach yield around 2 t/ha, the projected average value of 1.01 t/ha in 2050 is still likely to be achieved. Furthermore, due to high competition from other income generating activities, cocoa plantations will have to reach at least 1 t/ha to be economically viable (van Grinsven, 2018). The trajectory of the ARIMA model follows a constant trend of between 0.4 and 0.5 tons per ha and arrives at 0.43 t/ha in 2050 vs. 1 t/ha forecast in IMPACT. Since there is extremely high uncertainty of the ARIMA forecast due to large volatility of the data, we suggest keeping the IPRs on the previous level for out of sample period.

Table 4 Results summary for cocoa yield forecasts in Indonesia

In sample (2012-2014)	MAPE	MAE
ARIMA	4.4	0.02
IMPACT	76.0	0.31
Out of sample (2015-2050)	**CAGR**	**2050 yield (t/ha)**
ARIMA	0.29%	0.43
IMPACT	0.88%	1.00

Source: Own calculation

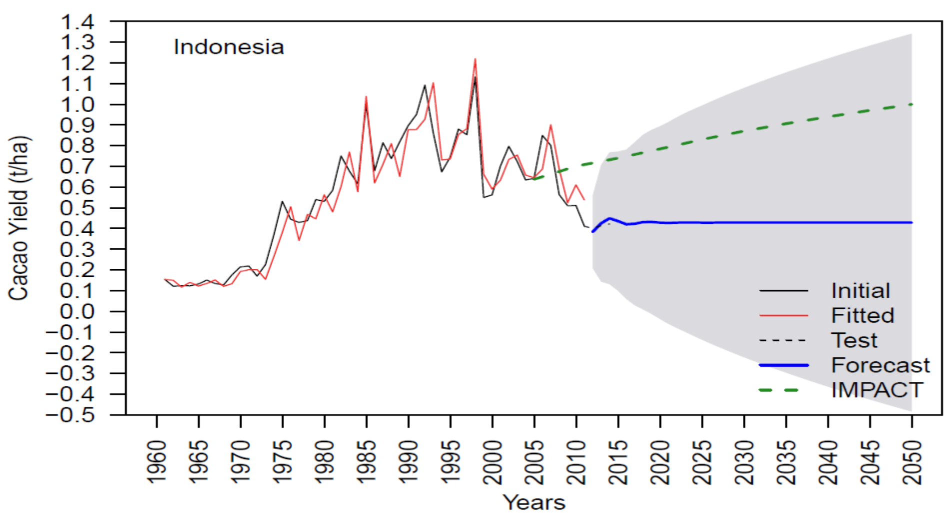

Figure 4 Cocoa yield forecast for Indonesia
Source: Own calculation

3.4 Cameroon

Cameroon has historically been one of the world's largest producers of cocoa, growing 291,512 tons in 2016 (FAOStat, 2018). Cocoa production occupies around 37% of current agricultural land and it is the major agricultural export crop (Ngoe, Li, Mukete, & Bobyeg, 2018). The Southwest, Centre, South, Littoral, East and West are the cocoa producing regions of Cameroon mainly consisting of small farms of about 1-3 ha (Traoré, 2009). Smallholders often cultivate cocoa in agroforestry systems in association with staple food crops such as maize and cassava (Traoré, 2009). Plantations are characterized by low yields, old trees and an average age of producers estimated in 63 to 70 years depending on the region (Sommeregger & Wildenberg, 2016). Differently from *Côte d'Ivoire* and Ghana, Cameroon completely liberalized cocoa market in the mid-1990s. As a consequence, the government has no control over the cocoa price at the farm gate, that is directly influenced by world market prices (Hütz-Adams et al., 2016). The FAO statistics show an unstable but net increment of cocoa production over the years, as a result the production has more than doubled in the last twenty years, shifting from 122.6 thousand tons in 2000 to 291.5 in 2016 (FAOStat, 2018). Most of the increase in production is due to an important expansion of the agricultural area dedicated to cocoa, but also yields have been steadily increasing over the years. Still, the yield performance was around 0.4 tons per ha in 2016, which is very low as compared to the top countries in cocoa production and below the world's average. The ageing of the cocoa plants, just as in the other West African countries, was identified as a major factor, followed by an inadequate input supply system and high rainfall seasons that caused the spreading of diseases like black pod (Wessel & Quist-Wessel, 2015).

The statistical analysis detected one level shift downwards in 1975 and two additive outliers in 1976 and 1995 and the selected intervention model for Cameroon is an ARIMA(0,1,0) with a drift.

$$\Delta y_t = 0.0049 - 0.0860 LS_{1975} - 0.0592 AO_{1976} + 0.0487 AO_{1995} + \epsilon_t$$

Neither IMPACT nor ARIMA capture the yield growth reported since 2012. Also, both models have similar in-sample forecast errors (table 5). However, the out of sample forecasts follow slightly different trajectory with an upwards trend towards 2050 in ARIMA, reaching values of 0.55 tons per ha in 2050. Whereas IMPACT shows a slower increase in yields until 2040 and slight decline afterwards, stopping on the level slightlyy above 0.4 tons per ha in 2050 (figure 5).

In 2014, the government of Cameroon has launched the Coffee and Cocoa Recovery Plan-Horizon 2020 (*Plan de Relance et de Développement des filières. Cacao et Café au Cameroun à l'horizon 2020*), setting a target of cocoa production equal to 600,000 tons by 2020. The plan is focused on research initiatives, productivity and production implementation, processing and commercialization of cocoa (Hütz-Adams et al., 2016). Considering the current yield level and the forecasts by IMPACT and ARIMA, the target is very unlikely to be achieved. However, it is likely that the yield will be slightly increasing until 2050. We suggest adjusting the current IPRs to match yield values forecasted by ARIMA.

Table 5 Results summary for cocoa yield forecasts in Cameroon

In sample (2012-2014)	MAPE	MAE
ARIMA	9.1	0.04
IMPACT	9.2	0.04
Out of sample (2015-2050)	**CAGR**	**2050 yield (t/ha)**
ARIMA	1.1%	0.55
IMPACT	0.27%	0.41

Source: Own calculation

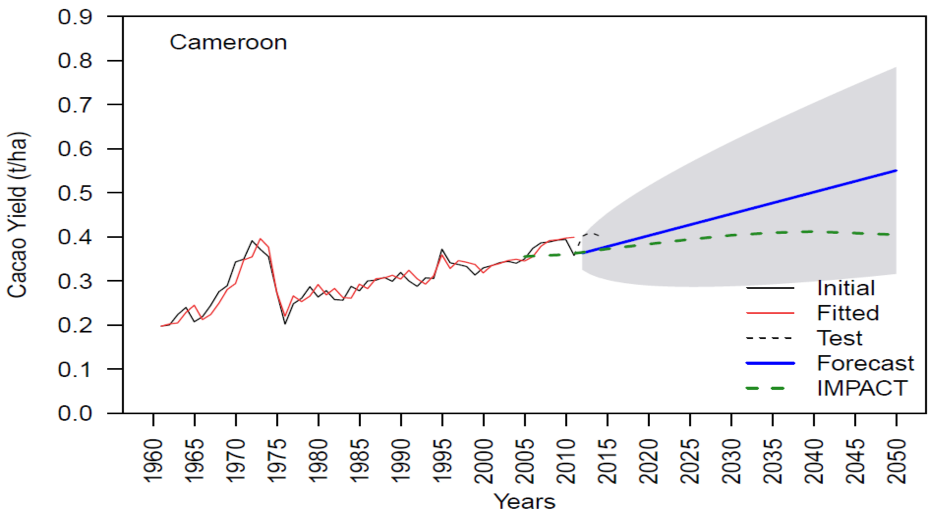

Figure 5 Cocoa yield forecast for Cameroon
Source: Own calculation

3.5 Nigeria

While still at the fifth position among the world's top producer, the Nigerian cocoa sector has experienced a steady decrease in recent years. However, cocoa is still the first agricultural export crop in Nigeria and the second most important export commodity, behind petroleum (WTO, 2018). 93% of Nigerian cocoa exports are in the form of raw beans, because of the limited processing activity within the country (Cadoni, 2013; FAOStat, 2018). Cocoa production takes place mostly in the country's rainforest and the main producing states are: Ondo, Ekiti, Oyo, Osun, Ogun, Delta, Edo, Cross-Rivers and Akwa Ibom (Oyekale, *et al.* 2009).

The total production has decreased from 485 thousand tons produced in 2006 to 236.5 t in 2016 (FAOStat, 2018). Nigeria is among the countries experiencing the lowest productivity rates in West Africa, even though the region is in general registering low performances (FAOStat, 2018). The main factors behind low yields in the last decades are: aging of farmers, between 50 and 60 years old on average, and trees over 40 years old. Among other relevant factors are the incidence of diseases and pests incidence, little agricultural mechanization and lack of agricultural extension (Cadoni, 2013; Hütz-Adams et al., 2016; Nwachukwu, Agwu, Nwaru, & Imonikhe, 2010). In 2017, Nigerian Federal government has set a target of 500.000 MT of production to be achieved by 2021 and announced the intention to invest and re-launch cocoa sector and agriculture in general through a new set of reforms (Africa International Trade & Commerce Research, 2017).

The intervention model selected for Nigeria is ARIMA(1,0,1) with a constant and contains one additive outlier in 1995:

$$y_t = 0.3195 + 0.8414y_{t-1} - 0.1645AO_{1995} + \epsilon_t - 0.3733\epsilon_{t-1}$$

This means that there was no trend in the data detected and the yields have been moving around a constant value. This has implications for the forecasted values, which stabilize on the level of 0.32 t/ha.

Table 6 Results summary for cocoa yield forecasts in Nigeria

In sample (2012-2014)	MAPE	MAE
ARIMA	27.7	0.05
IMPACT	86.4	0.20
Out of sample (2015-2050)	**CAGR**	**2050 yield (t/ha)**
ARIMA	0.07%	0.32
IMPACT	0.83%	0.62

Source: Own calculation

Since 1960, cocoa yield performances have been rather unstable ranging between 0.2-0.5 t/ha. Since 2009 Nigeria has been the country with the lowest yield among the ten biggest producers (figure 1). As shown in figure 6, IMPACT and ARIMA follow two very different trajectories. Neither models capture the sharp decline in the yield occurring since 2013. Further, the ARIMA out of sample forecast is much lower than the one in IMPACT (table 6). While ARIMA forecasts a constant trend until 2050 around a level of 0.3 tons per ha, the IMPACT scenario shows an unlikely growing trajectory, towards a level of 0.6 tons per ha and is never inside of the ARIMA prediction interval. It is very unlikely that the yield levels will catch up with the IMPACT forecast. Taking into account current low soil management and aging of trees that have caused a significant drop in yields in the last years and high uncertainty about the data quality, we propose adjusting the IMPACT IPRs to match the observed in-sample values and after 2015 keeping the IPRs unchanged, which will retain the slight upward trend until 2050.

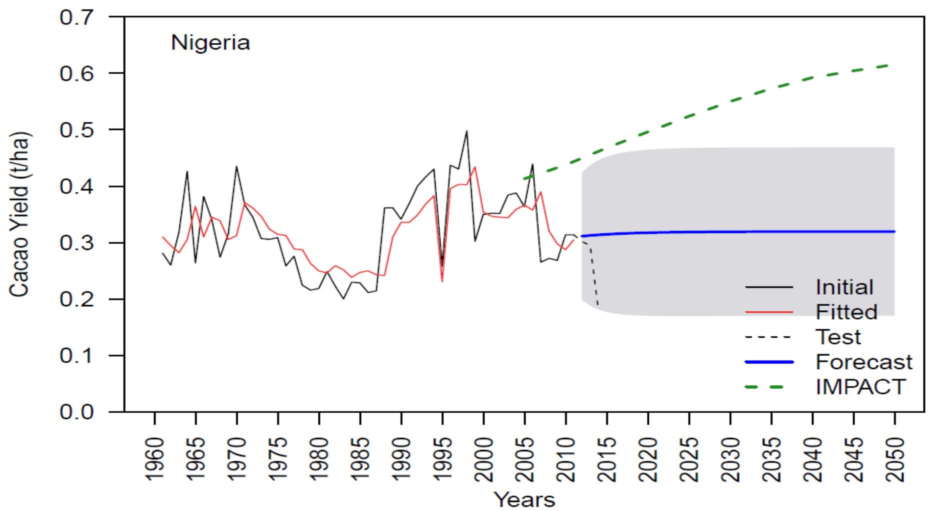

Figure 6 Cocoa yield forecast for Nigeria
Source: Own calculation

3.6 Brazil

Once a major cocoa producing country, Brazil is still the main producer in Latin America, but now it occupies only the sixth position in the world's top ten (FAOStat, 2018). Brazilian cacao production collapsed in the late 1980s due to an outbreak of Witches' Broom that devastated plantations and caused job loss for around 200,000 workers (Hütz-Adams et al., 2016; Poelmans & Swinnen, 2016). The disease is now endemic in several regions of the country and it has caused the abandonment of thousands hectares of several cacao farms (Teixeira *et al.*, 2015). In the last fifteen years, production has been slightly growing pushed by an increasing domestic demand and important research implementations supporting farmers with better pest and disease management practices (Pekic, 2014). However, it has never recovered from the dramatic collapse that occurred in the early nineties: Brazil' s production has halved from about 459 thousand tons produced in 1986 to about 213 thousand tons in 2016 (FAOStat, 2018).

Unlike the other major cocoa producers, the internal demand of cocoa is significant, and the country has developed a strong cocoa processing industry. Brazil became a net cocoa beans importer in 1997 (FAOStat, 2018) and it has the highest cocoa per capita consumption in Latin

America (Pekic, 2014). However, compared with Ecuador and other Latin American countries, the production of fine cacao is low.

According to data provided by the Brazilian Institute for Geography and Statistics (IBGE, 2018), cocoa yield varies consistently between different states. Bahia, traditionally the leading area for Brazilian cocoa plantations, was overtaken in 2017 by Pará as the main cocoa producing state. Yield is definitely the major factor: while the new plantations in Pará have registered a level of 0.88 tons per ha, in Bahia it is only around 0.20 tons per ha, well below the country average of 0.30 tons per ha (FAOStat, 2018; IBGE, 2018). This is mainly due to aging of cocoa trees and the spread of Witches' Broom in Bahia. The cocoa yield time series for Brazil contains one additive outlier in 1990 and the intervention model selected was ARIMA(0,1,3).

$$\Delta y_t = -0.1331AO_{1990} + \epsilon_t - 0.4387\epsilon_{t-1} + 0.0827\epsilon_{t-2} + 0.3528\epsilon_{t-3}$$

The reported yields for 2005-2014 are well approximated by the IMPACT model forecast. Moreover, as shown by figure 7, both IMPACT and ARIMA forecast the same yield trajectory until 2050. The predicted trend is steadily set around 0.34-0.38 tons per ha, reaching 0.39 t/ha with ARIMA and 0.35 t/ha with IMPACT in 2050 (table 7).
Considering the growing domestic demand, Brazilian government is supporting measures to boost cocoa yields, aiming to become a net exporter in the near future. In 2017, within the Executive Committee of Cocoa Farming Plan (COPLAC), Brazil invested 2.13 billion of Brazilian reals to support cocoa production in agroforestry system, in actuation of the Low Carbon Agriculture Plan (MAPA, 2017a). Considering the availability of inputs, planting material and government support, and that Pará's young plantations will possibly accelerate yield soon, an even better performance is to be expected towards 2050 (van Grinsven, 2018).

However, According to the Long-term Agribusiness Forecast for 2026/2027, published in 2016 by Brazil's Ministry of Agriculture, Livestock Production and Supplies (MAPA), the predictions for the future of cocoa in Brazil are moderately optimistic (MAPA, 2017b). This forecast assumes production growth by 9.5% in the next ten years and reduction of the harvested area equal to 2%. According to this report, the yields will be then slightly increasing by 2026/27 reaching the 0.39 tons per ha. This scenario is aligned with the trajectories from IMPACT and ARIMA simulations. As a result, we recommend no adjustments to the IPRs until 2030, and afterwards introducing a slight upward trend until 2050.

Table 7 Results summary for cocoa yield forecasts in Brazil

In sample (2012-2014)	MAPE	MAE
ARIMA	1.3	0.00
IMPACT	6.7	0.03
Out of sample (2015-2050)	**CAGR**	**2050 yield (t/ha)**
ARIMA	0.17%	0.39
IMPACT	0.05%	0.35

Source: Own calculation

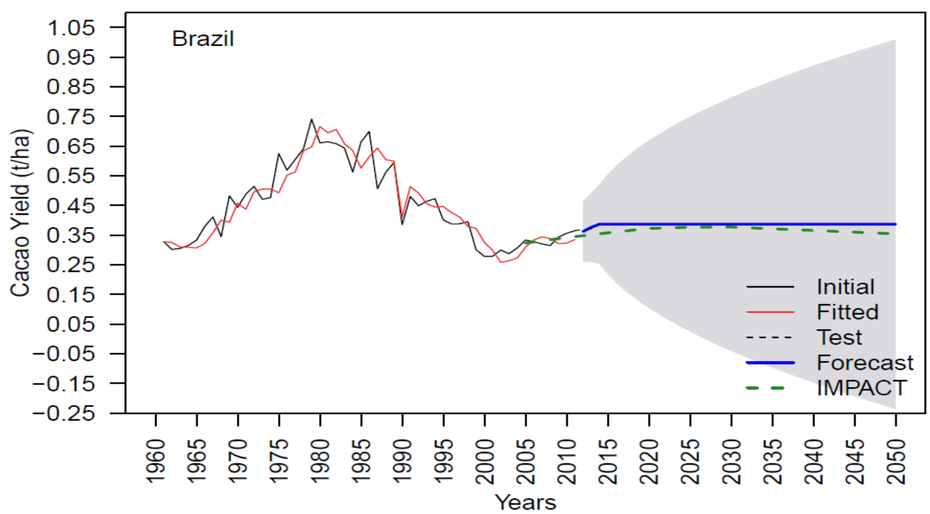

Figure 7 Cocoa yield forecast for Brazil
Source: Own calculation

3.7 Ecuador

Ecuador is the seventh largest global cocoa producer in terms of total volume of production (FAOStat, 2018), and at the same time it is the first producer and exporter of Fine Flavour Cocoa (FFC) with a 65% share of the market (van der Kooij, 2013). In Ecuador, about 100,000 families are involved in cocoa production. Most of them are smallholders, with less than 5 ha (Lehmann & Springer-Heinze, 2014), however they contribute to around 80 to 90% of total Ecuadorian cocoa production (Hütz-Adams et al., 2016). Manabí, Los Ríos, and Guayas provinces concentrate 80% of total Ecuadorian production (Vega & Beillard, 2015). While the native Arruba plantations, a fine flavour cocoa variety, have been revitalized, the country is still unable to take full advantage of the existing market potential. At the same time, in recent years Ecuador has also increased cultivation of the high-yielding and disease-resistant clone, CCN-51 (Vega & Beillard, 2015). In general, there is a need for more orientation towards product quality (certifications, unique origin varieties, adequate post-harvest handling and treatment), yield improvement, strengthening of farmers' association and provision of agricultural services (Lehmann & Springer-Heinze, 2014).

Until 2010 cocoa productivity in Ecuador was relatively low and constantly below the value of 0.35 tons per hectare. This is mainly due to the high incidence of Witches' Broom and Frosty Pod Rot (*Moniliophthora roreri*) (Vega & Beillard, 2015). The only exceptions, in 1968, 1974 and 1985, have all been detected as outliers. In 2016, cocoa yield has reached the value of 0.39 tons per hectare. This is still below the global standard, but also encouraging if considering that between 1961 and 2016 the country average has been around 0.28 t/ha (FAOStat, 2018).

The intervention model selected to describe the evolution of cocoa yields in Ecuador is the following ARIMA(0,0,0) with a constant:

$$y_t = 0.2595 + 0.1297AO_{1968} + 0.1239TC_{1974} + 0.1940AO_{1985} - 0.1429AO_{1998} + 0.3017AO_{2011} + \epsilon_t$$

This means that there were no detected systematic deviations from the constant value, except for the outliers.

Table 8 Results summary for cocoa yield forecasts in Ecuador

In sample (2012-2014)	**MAPE**	**MAE**
ARIMA	26.9	0.10
IMPACT	24.1	0.09
Out of sample (2015-2050)	**CAGR**	**2050 yield (t/ha)**
ARIMA	0.00%	0.26
IMPACT	0.78%	0.36

Source: Own calculation

As presented in figure 8, since 2010 cocoa yields in Ecuador have started showing a better performance. In the last decade, Ecuadorian cocoa productivity has increased remarkably and Ecuador is currently considered among the countries with the highest potential in the future (van Grinsven, 2018). Neither ARIMA, nor IMPACT capture recent spike (table 8). The ARIMA forecast is still below 0.3 tons per hectare, while in the IMPACT scenario, it grows steadily up to 0.36 t/ha in 2050. Cocoa has a key importance in Ecuador and it is considered as a strategic factor for the economic development of the country (Hütz-Adams et al., 2016). In 2012, the Ecuadorian government has launched the High Quality Aromatic Cocoa Reactivation Project (Ministerio de Agricultura y Ganadería del Ecuador, n.d.), focused especially on the professionalization of small and medium producers. Special attention is dedicated to supporting the quality and productivity of FFC cultivation, although also the interest in high-yielding variety CCN-51 has been growing. Taking into consideration the recent farms renovation, yield improvements and the future targets set by the Ecuadorian government, the ARIMA forecast appears to be underestimated (van Grinsven, 2018).We recommend shifting the IPRs upwards to match the observed yield levels for the in sample forecast and keep the out of sample forecast on the previous level, following the upward trend.

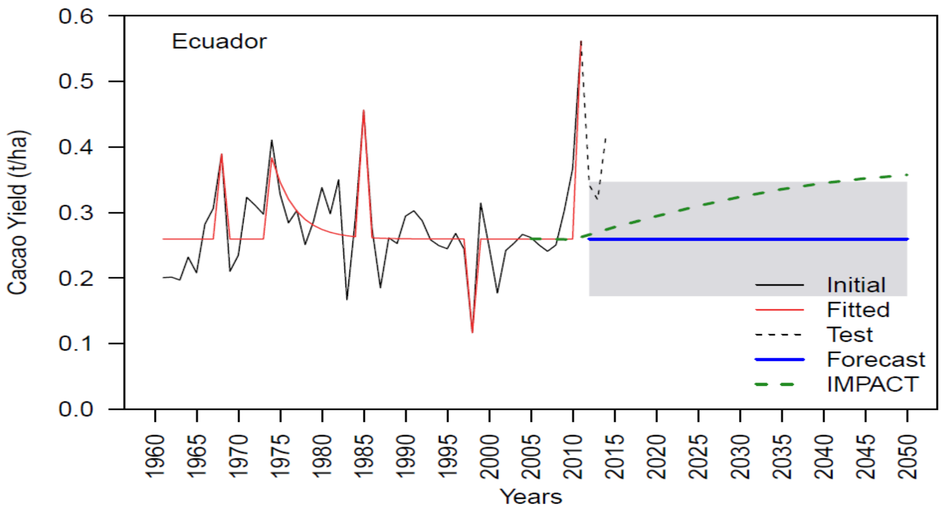

Figure 8 Cocoa yield forecast for Ecuador
Source: Own calculation

3.8 Peru

In Peru, cocoa production has been strongly growing in the last 10 years, doubled since 2008, and currently the country is the eighth largest cocoa producer in the world (FAOStat, 2018). Peru is also emerging as the second largest producer of Fine Flavour Cocoa (FFC), after Ecuador. As in the case of Ecuador, the strength of the Peruvian cocoa sector relies on its wide diversity. In 2016, the production reached 107.92 thousand tons, and the 75% of the export was classified as FFC (ICCO, 2017). International support to eradicate coca and the increase in international cocoa price has resulted in a cocoa area expansion (Kieck, Zug, Huamaní Yupanqui, Gómez Aliaga, & Cierjacks, 2016). Processing capacity and the local chocolate industry have also shown a relative growth, but there is still room for improvement.

Several government and private initiatives have been put in place to increase the quality of the cocoa produced and achieve Fair Trade and organic certifications. Integrated pest management practices (IPM) were at the core of the government interventions to control and reduce pest incidence, namely Witches' Broom and Frosty Pod Rot, but the adoption rates of IPM by farmers were marginal. Yield varies significantly among the different regions and different farms, ranging from 0.25 t/ha to 2.5 t/ha. San Martin is the region where the highest yields are obtained, followed by Junín region (Hütz-Adams et al., 2016). Farm size, disease incidence, climatic conditions and variety of the plants are the reasons behind the gaps in productivity (Scott, Donovan, & Higuchi, 2016). In 2001, Peru yields were equal to 0.517 tons per ha, while in 2016, the country registered a level of 0.859 tons per ha, somewhat above the global average. Adoption of the high yielding CCN51 cocoa variety is considered to be the main factor for the recent positive performances of the sector (ibid). Since 2010, Peru has been the country with the highest productivity rate among the 10 biggest cocoa producers (FAOStat, 2018), Côte d'Ivoire is the second with 0.516 t/ha.
The analysis of the outliers has revealed two additive outliers (1964 and 1996) and one level shift in 1995. The selected model was the following ARIMA (0, 0, 3) with a constant:

$$y_t = 0.5015 + 0.1079AO_{1964} + 0.0784LS_{1995} + 0.0904AO_{1996} + \epsilon_t + 0.5880\epsilon_{t-1} + 0.6682\epsilon_{t-2} + 0.4805\epsilon_{t-3}$$

This model means that there was no trend detected in the data and the observations were oscillating around the constant value of 0.5 t/ha plus the outliers.

Table 9 Results summary for cocoa yield forecasts in Peru

In sample (2012-2014)	**MAPE**	**MAE**
ARIMA	14.0	0.11
IMPACT	22.1	0.16
Out of sample (2015-2050)	**CAGR**	**2050 yield (t/ha)**
ARIMA	-0.32%	0.58
IMPACT	1.08%	0.86

Source: Own calculation

Figure 9 shows that yield in Peru has been strongly growing since 2005 but neither of the models has managed to capture it. Forecast for 2012-14 is more accurate in case of the ARIMA model (table 9) because it used more recent data that captured improved yield performance. IMPACT and ARIMA follow different pathways towards 2050, with the latter following a decreasing trend until 2015 and then a flat trajectory among 0.55-0.6 t/ha. IMPACT instead, forecasts steadily growing yields, reaching 0.86 t/ha in 2050. Experts expect even higher yield growth, leading to a potential of around 1 t/ha (van Grinsven, 2018). Considering recent positive performance, a very supportive government and the growing international interest, the future scenario seems to be optimistic for yields and the Peruvian cocoa sector in general (Pekic, 2015; Scott et al., 2016). We recommend adjusting the IPRs so that they capture the intense yield growth after 2005, however the growth rate after 2015 should slightly slow down, so that as a result the yield stabilizes on the level close to between 0.9 t/ha and 1 t/ha.

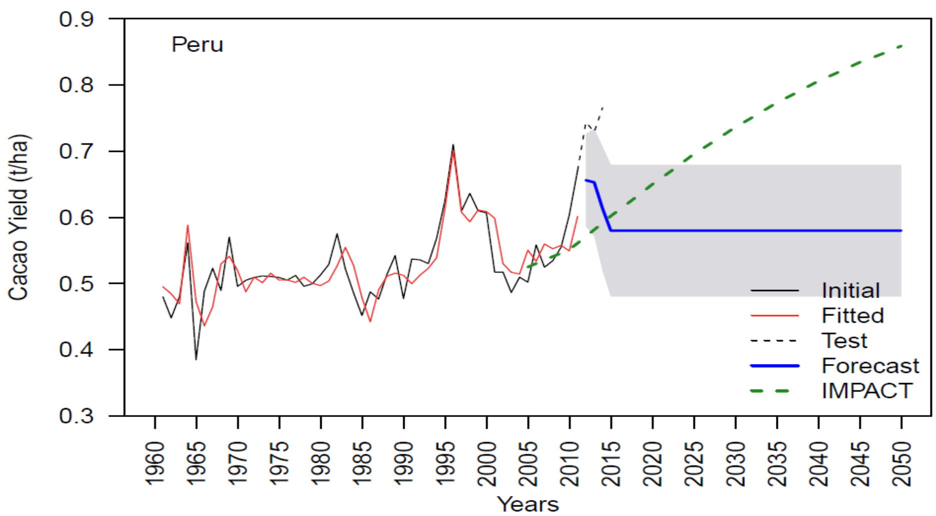

Figure 9 Cocoa yield forecast for Peru
Source: Own calculation

3.9 The Dominican Republic

The ninth cocoa producer in the world with 81,246 tons in 2016 (FAO Stat, 2018), is dedicated to sustainable cocoa production. According to FAOStat (2018), cocoa is the largest crop cultivated in the Dominican Republic in terms of land use and the government works to ensure environmentally sustainable cocoa cultivation. The country is the world's leader in Fair Trade cocoa exports. The producers are mainly small holders with an average farm size of 3 ha, although larger cocoa land holdings are becoming more frequent. Over 10,000 of a total of 40,000 farmers produce organic cocoa. The Dominican Republic is the major exporter of organic cocoa that accounts for about 20% of the total cocoa export of the country (Nieburg, 2016). The main final destinations are the US and the European markets.

The Dominican Republic is part of the "Hurricane Belt" and this has greatly affected cocoa productivity throughout the period analysed. The yield shown in figure 10 is very volatile. However, after a significant decrease between the end of the 1990s and the mid-2000s, yields have improving since 2005 (figure 10). Currently, the Dominican Republic is the fourth country among the ten biggest producers in terms of yield performance, averaging at 0.47 tons per ha in 2016 (FAOStat, 2018). Within the country, yields are estimated to vary between 0.25-1.50 t/ha. Central region reaches the highest levels of production, followed by the East and the North-East (Berlan & Bergés, 2013). The government has banned the cultivation of high-yielding variety CCN-51 to protect plantations from the risk of importing diseases, such as Witches' Broom, which has never affected the trees present in the country (Nieburg, 2016). The government has also launched a ten-year National Action Plan from 2017 in partnership with the UNDP's Green Commodities Programme. The objective is to triple yields in the next decade, stating that reaching a level of 1-1.5 t/ha for the majority of the farmer is a possible (Cuello *et al.* 2015)

Time series analysis of the yield detected four outliers: one additive outlier in 1964, one positive level shift in 1989 and two negative transitory changes 1999 and 2005. The latter two, were the consequence of two devastating hurricanes: Hurricane George (1998), one of the worst environmental disasters to have ever affected cocoa plantations, and Hurricane Jeanne (2004), less powerful but still highly damaging (Berlan & Bergés, 2013). The intervention model selected for this country is ARIMA (0, 1, 1):

$$\Delta y_t = 0.1036AO_{1964} + 0.1048LS_{1989} - 0.2027TC_{1999} - 0.1775TC_{2005} + \epsilon_t - 0.5038\epsilon_{t-1}$$

Table 10 Results summary for cocoa yield forecasts in Dominican Republic

In sample (2012-2014)	**MAPE**	**MAE**
ARIMA	21.5	0.10
IMPACT	31.4	0.15
Out of sample (2015-2050)	**CAGR**	**2050 yield (t/ha)**
ARIMA	0.00%	0.36
IMPACT	0.33%	0.36

Source: Own calculation

As it can be seen in figure 10 and from the in-sample errors in table 10, both models underestimate the recent increase in yields. The ARIMA forecast trajectory steadily proceeds around 0.4 t/ha, while the IMPACT scenario shows a slight increase in yields, catching up with the ARIMA values by 2050.

Even though the high risk of environmental disaster will always be an issue for cocoa plantations in the Dominican Republic and will result in periodic drops in production, the trend will most probably be of a steady growth. As a result, we propose adjusting the IPR upwards in order to capture the new level of registered yields and further adjusting the forecast upwards so that the yield level reaches 0.7-0.8 t/ha in 2050.

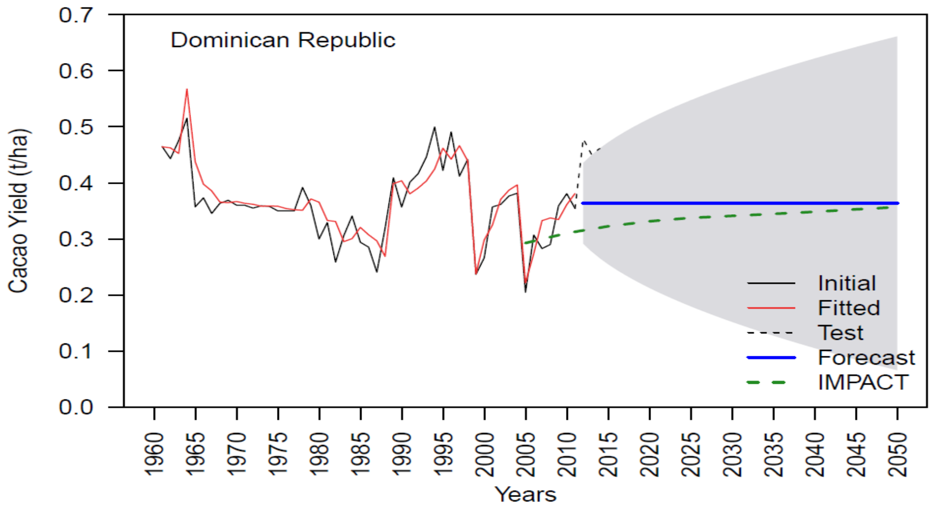

Figure 10 Cocoa yield forecast for Dominican Republic
Source: Own calculation

3.10 Colombia

Colombia is currently the tenth cocoa producer worldwide and approximately 90% of the produce is grown by smallholders, with an average plot size of 3.3 ha (Espinal *et al.*, 2005; Procolombia, 2012). The region of Santander is the main region for cocoa production in Colombia, accounting for 40% of the total (Ministerio de Agricultura y Desarrollo Rural de Colombia, 2012). Smallholders generally cultivates cocoa in agroforestry systems, in association with other crops, mainly coffee, plantains or timber species. This provides them with alternative source of income (Espinal *et al.* 2005).

Between the early 2000s and 2012, the Colombian chocolate industry consumed all its domestic cocoa production. In the recent years, however, thanks to a strong increase in domestic production Colombia has become a net exporter (FAOStat, 2018; García-Cáceres, Perdomo, Ortiz, Beltrán, & López, 2014). Fine flavour cocoa represents 95% of total Colombian cocoa exports (ICCO, 2017). The efforts of the farmers, the government and international agribusiness development entities have made cocoa, and particularly FFC, a good alternative for farmers to illegal coca cultivations, as in the case of Peru (Procolombia, 2014). In 2012, the Colombian government launched program "Cocoa Development Ten Year Plan 2012-2021", setting ambitious targets such as renewing an area of 130,000 hectares with selected clones and modern techniques of management by 2016, an annual production of 156,000 tons by 2020, and export 50% of domestic production (García-Cáceres et al., 2014; Ministerio de Agricultura y Desarrollo Rural de Colombia, 2012).

Consequently, the harvested area for cocoa cultivation has considerably increased moving from 102.9 thousand hectares in 2012 to 165.8 ha in 2016, and so has the production - from 41.7 thousand tons to 56.2 thousand tons in 2016. However, in the same period yields have strongly decreased registering the lowest levels since 1961 (FAOStat, 2018). According to FAO Stat data, between 1961 and 2010, cocoa yields in Colombia have always been in a range of 0.40-0.56 tons per ha, while since 2011, with an exception of 2012, it has been below 0.4 t/ha. The major reasons for the decrease can be identified in the old hybrid material grown in the majority of plantations (Ortiz-R. *et al.* 2014), low cocoa local price, and the spread of pests and diseases (Espinal *et al.*, 2005). Currently the government, within the Production Transformation Program (PTP), is directly pursuing the increase of productivity of cocoa plantation and it is currently releasing and supporting the propagation of new high productivity clones characterized by stability, grain size, precocity and resistance to disease (Procolombia, 2014).

The evolution of cocoa yields in Colombia is described by ARIMA (3, 0, 0) with two outliers - a positive transitory change in 1978 and a negative additive outlier in 2000:

$$y_t = 0.4616 + 0.9249 y_{t-1} - 0.7823 y_{t-2} + 0.2776 y_{t-3} + 0.1052 TC_{1978} - 0.0542 AO_{2000} + \epsilon_t$$

This model selection means that there was no deterministic or stochastic trend detected in that p eriod and consequently, the forecasted values stabilize on the level of the constant in the model - 0.46 t/ha.

Table 11 Results summary for cocoa yield forecasts in Colombia

In sample (2012-2014)	**MAPE**	**MAE**
ARIMA	35.3	0.11
IMPACT	59.8	0.19
Out of sample (2015-2050)	**CAGR**	**2050 yield (t/ha)**
ARIMA	0.32%	0.46
IMPACT	1.14%	0.79

Source: Own calculation

Figure 11 shows that the IMPACT projection could not capture the drop in cocoa yields in the last five years and neither could the ARIMA forecast. The trajectories of the two models follow different paths: while ARIMA steadily proceeds towards 2050 to around a value of 0.45 t/ha, the IMPACT model is fairly optimistic, especially if compared to the recent trend, by forecasting a level of coca yields almost reaching 0.8 t/ha in 2050 (table 11).

Despite the recent poor outcomes, considering the ambitious targets set by the Cocoa Development Ten Year Plan 2012-2021, the growing cocoa demand, especially for FFC, it is likely to expect better performances for the next years. Colombia still needs to address key aspects in cocoa production, such as crop quality and crop productivity, as well as the renovation of ageing trees. We recommend adjusting the IPRs to match the observed values of yields until 2014, and after 2018 introducing a gradual growth to match values around 0.6-0.7 t/ha in 2050.

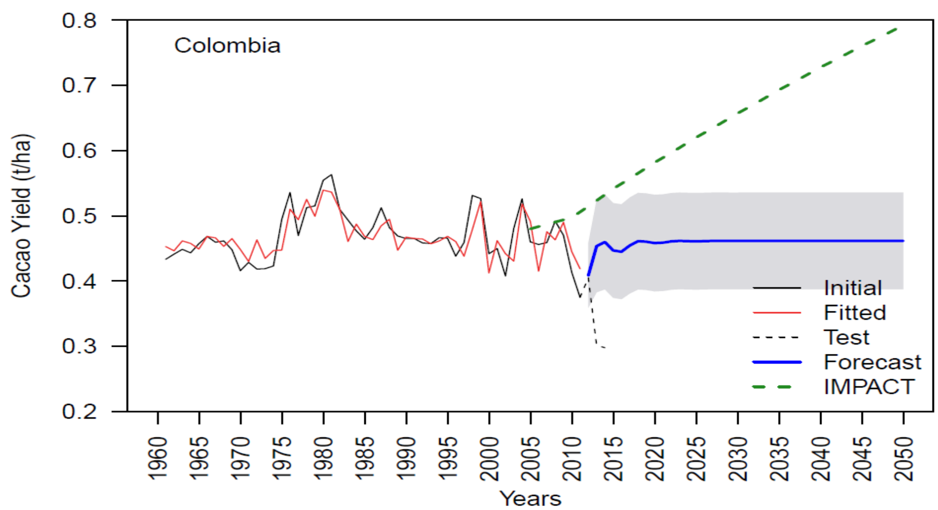

Figure 11 Cocoa yield forecast for Colombia
Source: Own calculation

4. Discussion and conclusions

This report outlines our systematic review and forecast cocoa yield developments in ten major producing countries. We base our forecasts on univariate time series model, ARIMA, literature review, policy analysis and expert knowledge in order to validate performance and possibly suggest corrections to the respective baseline yield trajectories embedded in IMPACT. Interventions either from policymakers or the industry providing access to resources appear to have a major impact on cocoa production and cocoa yields in particular. Hence, these interventions will play a key role in the future yield developments. As a result, it is very difficult to make log-term predictions. As a result, we propose several adjustments to the IPRs, which are summarized in table 12.

Table 122: Summary of results

Country	Recommendations
Côte d'Ivoire	Both the IMPACT and ARIMA forecasts follow a growing trajectory towards 2050, however IMPACT values are between 0.1 t/ha and 0.2 t/ha above the ARIMA

	generated numbers, which can be mostly attributed to the level shift in 2005 and that IMPACT did not capture. However, considering the high probability that data have been influenced by the smuggling activities between Côte d'Ivoire and Ghana, we suggest treating this downward shift in yield as an outlier. **We suggest adjusting the IPRs downwards to match the actual yields until 2014 and leaving the IPRs unchanged for the 2014-2050 forecasts.**
Ghana	Forecast errors for both models for 2012-14 give very high errors and both IMPACT and ARIMA did not detect the higher level of yields registered since 2012. This positive trend could then result in a new level shift upward. IPRs should be consequently adjusted but, bearing in mind that recent yield level increase could also be inflated by smuggled cocoa from Côte d'Ivoire to Ghana. **We suggest adjusting IPRs to match the observed yield values (until 2014) and lowering IPRs until 2050 in order to reach the yield levels slightly above currently forecasted in IMPACT** (0.51 t/ha)..
Indonesia	IMPACT has not captured the recent level shift downwards occurred in 2010 and its forecast errors are large, whereas ARIMA produced an accurate in sample forecast for 2012-14. Consequently, **IPRs should be adjusted 2010-2014**. IMPACT projection is within the 95% ARIMA forecast interval, however it is systematically above the ARIMA mean forecast. Overall, ARIMA model trajectory follows a constant trend of between 0.4 and 0.5 t/ha and arrives at 0.43 t/ha in 2050 vs. 1 t/ha forecast in IMPACT. Since there is extremely high uncertainty of the ARIMA forecast due to large volatility of the data and considering the potential for successful farmers to reach yield around 2 t/ha, **we suggest keeping the IPRs on the previous level for the period 2014-2050.**
Cameroon	Neither IMPACT nor ARIMA captured the yield growth reported since 2012 and the models have similar forecast errors. However, the out of sample forecasts follow a slightly different trajectory towards 2050. ARIMA reaches a value of 0.55 t/ha in 2050, whereas IMPACT shows a slower increase in yields until 2040 and a slight decline afterwards, towards the level of 0.4 t/ha in 2050. The target set by the Government of 600,000 t of production by 2020 is very unlikely to be achieved considering the current yield level and the forecasts by IMPACT and ARIMA. However, it is likely that the yield will be slightly increasing until 2050. **We suggest adjusting the current IPRs to match yield values forecasted by ARIMA** (0.55 t/ha in 2050)**.**
Nigeria	Since 1960, cocoa yield performances have been rather unstable ranging between 0.2-0.5 t/ha. IMPACT and ARIMA follow two very different trajectories: ARIMA model forecasts a constant trend until 2050 around a level of 0.3 t/ha, while the IMPACT

	scenario shows an unlikely growing trajectory towards a level of 0.6 t/a and is never inside of the ARIMA prediction interval. Taking into account currently low soil management and aging of trees that have caused a significant drop in yields in the last years and high uncertainty about the data quality, we **propose adjusting the IMPACT IPRs to match the observed values until 2014 and after 2015 keeping the IPRs unchanged, which will retain the slight upward trend until 2050.**
Brazil	The reported yields for 2005-2014 are well-captured in the IMPACT model forecast. Furthermore, both IMPACT and ARIMA forecast the same yield trajectory around 0.34 t/ha and 0.39 t/ha, reaching respectively 0.35 t/ha and 0.39 t/ha in 2050. Considering the availability of inputs, planting material and government support, and new plantation areas, an even better performance is to be expected towards 2050 . The Brazilian Ministry of Agriculture forecasts predict a scenario of 0.39 t/ha by 2026/27, in line with the trajectories from IMPACT and ARIMA. As a result, **we recommend no adjustments to the IPRs until 2030, and afterwards introducing a slight upward trend until 2050.**
Ecuador	In the last decade, Ecuadorian cocoa productivity has increased remarkably and Ecuador is currently considered among the countries with the highest potential in the future. Neither ARIMA, nor IMPACT capture recent spike. The ARIMA forecast is still below 0.3 t/ha, while in the IMPACT scenario, it grows steadily up to 0.36 t/ha in 2050. Taking into consideration the recent farms renovation, yield improvements and the future targets set by the Ecuadorian government, the ARIMA forecast appears to be underestimated. **We recommend shifting the IPRs upwards to match the observed yield levels until 2014 and keep the out of sample forecast on the previous level, following the upward trend.**
Peru	Cocoa yield in Peru has been strongly growing since 2005 but neither of the models has managed to capture it, while forecast for 2012-14 is more accurate in case of the ARIMA model because it used more recent data. IMPACT and ARIMA follow different pathways towards 2050. ARIMA forecast follows a decreasing trend until 2015 and then a flat trajectory among 0.55-0.6 t/ha, while IMPACT predicts steadily growing yields, reaching 0.86 t/ha in 2050. According to experts' expectations and recent positive performance, the future scenario seems to be optimistic. **We recommend adjusting the IPRs so that they capture the intense yield growth after 2005, however the growth rate after 2015 should slightly slow down, so that as a result the yield stabilizes on the level close to between 0.9 t/ha and 1 t/ha.**
Dominican Republic	Both models underestimate the recent increase in yields. The ARIMA forecast trajectory steadily proceeds around 0.4 t/ha, while the IMPACT scenario shows a slight increase in yields, catching up with the ARIMA values by 2050.

	Bearing in mind that the high risk of environmental disaster will always be an issue for cocoa plantations in the Dominican Republic, resulting in periodic drops in production, the trend will most probably be of a steady growth. As a result, **we propose adjusting the IPR upwards in order to capture the new level of registered yields and further adjusting the forecast upwards so that the yield level reaches 0.7-0.8 t/ha in 2050.**
Colombia	The IMPACT projection could not capture last five years drop in cocoa yields and neither could the ARIMA forecast. The trajectories of the two models follow different pathways: while ARIMA steadily proceeds towards 2050 to around a value of 0.45 t/ha, the IMPACT model prediction almost reaches 0.8 t/ha in 2050. The ambitious targets set by Colombian and the growing cocoa demand, especially for FFC, lead to expect better performances for the next years. **We recommend adjusting the IPRs to match the observed values of yields until 2014, and after 2018 introducing a gradual growth to match values around 0.6-0.7 t/ha in 2050.**

In our analysis we assume that cocoa yields follow a random process which can be separated into the 'signal' and 'noise' and that the signal contains information about all factors determining yield growth in the long term. Our model does not account for economic or biophysical relationships because no exogenous variables are explicitly considered. We further assume that the net effect of all the factors influencing yield in the future will follow the current average trend, which is in line with "business as usual" scenario assumptions. In this way, we base our conditional forecasts on signal extrapolation with ARIMA model, rather than make predictions about the yields in the future. Having that in mind, we use the available information about the new policies or any other new factors which might change the old yield trajectories to make the final recommendation.

As a general picture, smallholders in developing countries produce the majority of the world's cocoa, fighting problems like: ageing trees, degrading soils, pest and disease outbreaks and negative climate change effects, lack of access to quality inputs, low farm-gate prices. The world's average yield of cocoa is a little above 0.4 t/ha, well below the potential 3-5 t/ha. Even in main cocoa producing countries like Indonesia, Nigeria, Ecuador and Brazil cocoa yields are below the world's average. It is easy to understand that smallholders in these and other major producing countries are discouraged from investing time and resources in a crop that offers very low economic advantages. As a result, in the business as usual scenario, neither of the ten biggest producers is forecasted to exceed the average yield of 1 t/ha.

Advances in yield performance depend on the sustainability of the agronomic practices implemented. This is particularly critical for a permanent crop that stays in the field for more than 30 years in average. Yield-forecast-models need to capture the long-term effects of short-term economic decisions of farmers on their cocoa yields. Basic management practices that have been neglected due to low economic price can have a significant impact on the performance of the crop. The aging effect on productivity of a cocoa tree is accentuated when the crop is not properly fertilized, not shaded at early stages, or not treated against main pest or diseases. In a late stage of an average cocoa plantation, cocoa productivity is too low to sustain the producer who tends to replant shade and create an agroforestry system mainly as a way to diversify their income. Another strategy, which has been frequently used is to move into new land and plant new trees. However, this is decreasingly accessible as availability of new land for expending production is very low in most of the countries, especially in West Africa. As a result, farmland with poorer soil health will be a significant limiting factor to yield growth.

The production of new cocoa varieties with higher yield and resistant to pest and diseases is particularly relevant in a scenario where the cocoa consumption is increasing and climate change becomes more evident. The impacts of climate change on cacao production needs to be better understood and elucidated. The integration of crop production, and market and climatic models is an interesting alternative to address this research need.

A wider use of cocoa diversity should be considered as part of these efforts, as well in the efforts to deal with the potential impact of climate change. The cocoa industry has historically developed its cultivation of mainly three cocoa types. The scientific evidence however, reveals that cocoa diversity is greater than that currently used and thus is largely unexploited (Motamayor et al., 2008). Latin America although not the main producing region, is the centre of origin and diversity of the crop. A small part of this diversity is kept in field gene banks, but the larger part is kept in natural ecosystems exposed to potential loss. Based on this rich diversity, Latin America has become an important source of fine flavour cacao. The conservation of cacao genetic diversity therefore is critical, given the growing interest in unique flavours and health properties, as well as the need to search for new varieties that show resistance to biotic and abiotic stresses and can help achieve better yields.

The industry is concerned about accessing a steady supply, and so is responding by implementing and funding projects that promote access to resources, support research, and improve technology transfer. These interventions, in collaboration with local governments seem to be having a significant impact on cocoa production and cocoa yield in particular. Their effects have not been yet captured by the ARIMA forecast / IMPACT model. We speculate that these interventions will play a key role in the future yield developments. There is still however a lot of work to be done to improve the productivity of cocoa. In general, the predictions seem to be alarming, as in most of the cases the ARIMA yield forecasts show basically no yield improvement. In a few cases yield even decreases. We want to reiterate the need for diversity conservation not only to improve the quantity produced but also to improve its quality.

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APPENDIX A: OUTLIERS AND ADJUSTMENTS IN COCOA YIELD SERIES

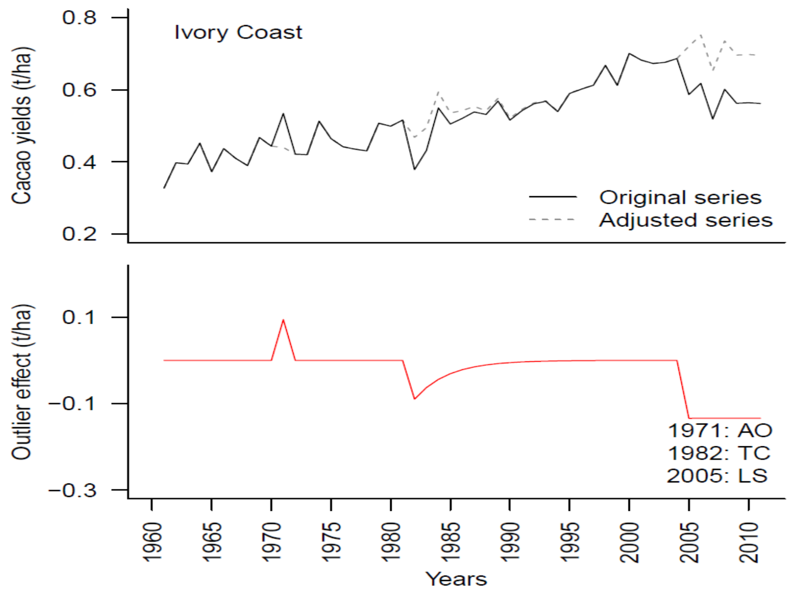

Figure 12 Outliers of the cocoa time series in Côte d'Ivoire between 1960 and 2014

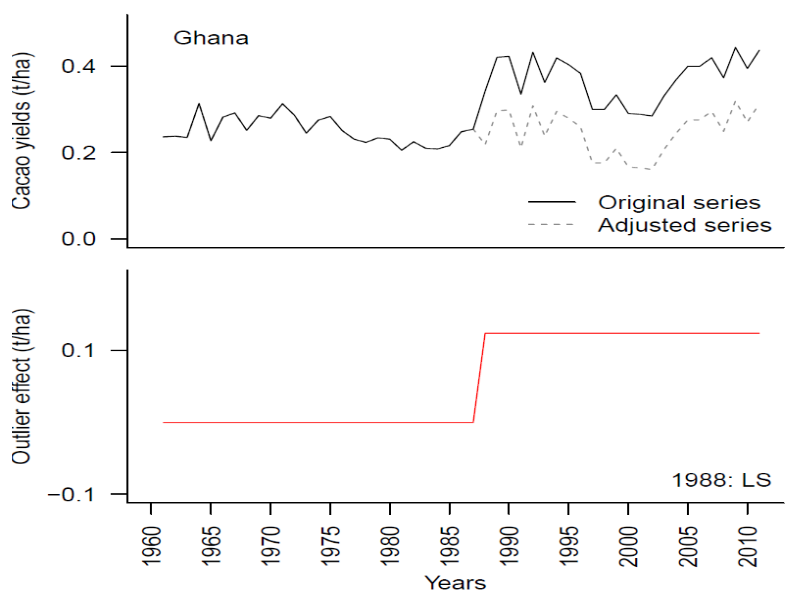

Figure 13 Outliers of the cocoa time series in Ghana between 1960 and 2014

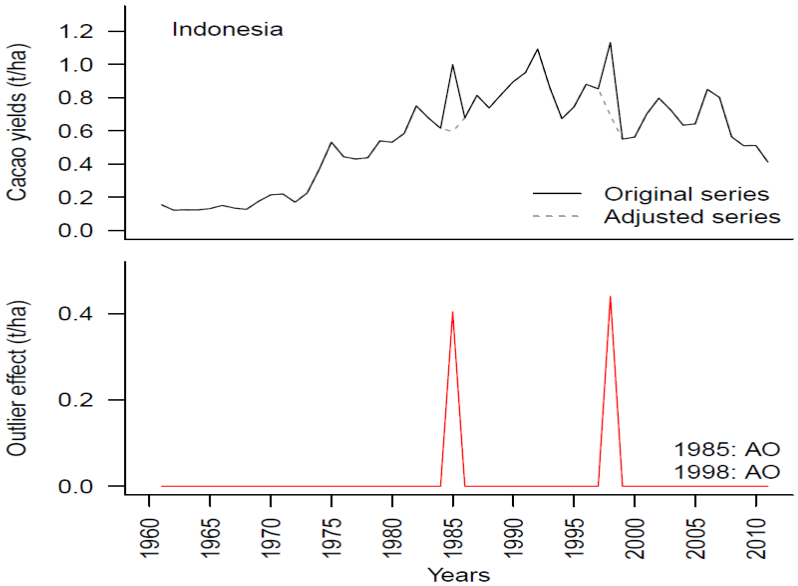

Figure 14 Outliers of the cocoa time series in Indonesia between 1960 and 2014

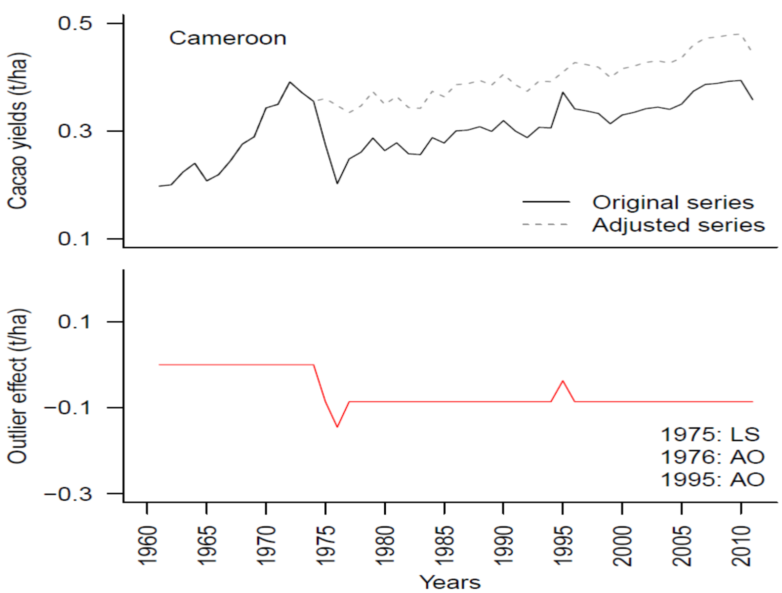

Figure 15 Outliers of the cocoa time series in Cameroon between 1960 and 2014

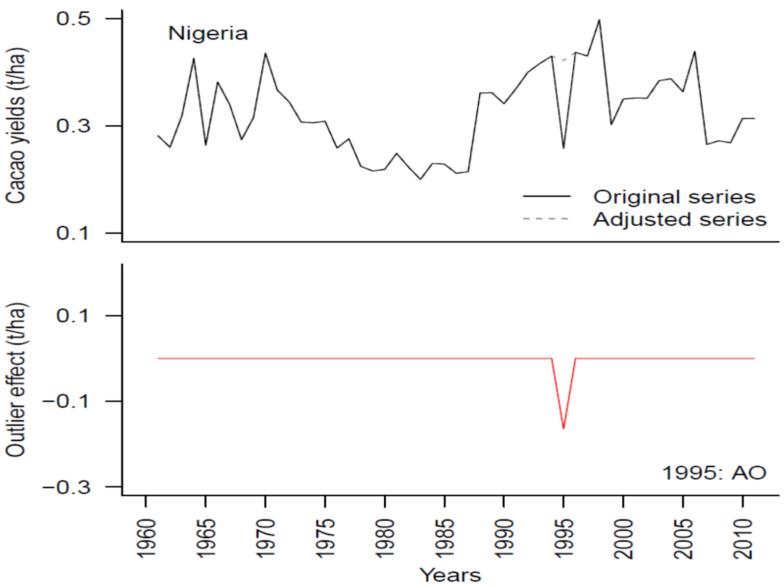

Figure 16 Outliers of the cocoa time series in Nigeria between 1960 and 2014

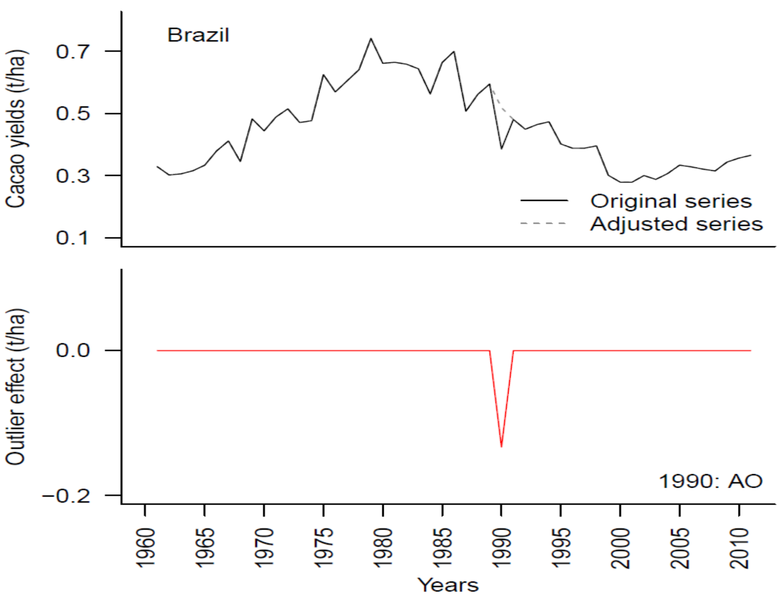

Figure 17 Outliers of the cocoa time series in Brazil between 1960 and 2014

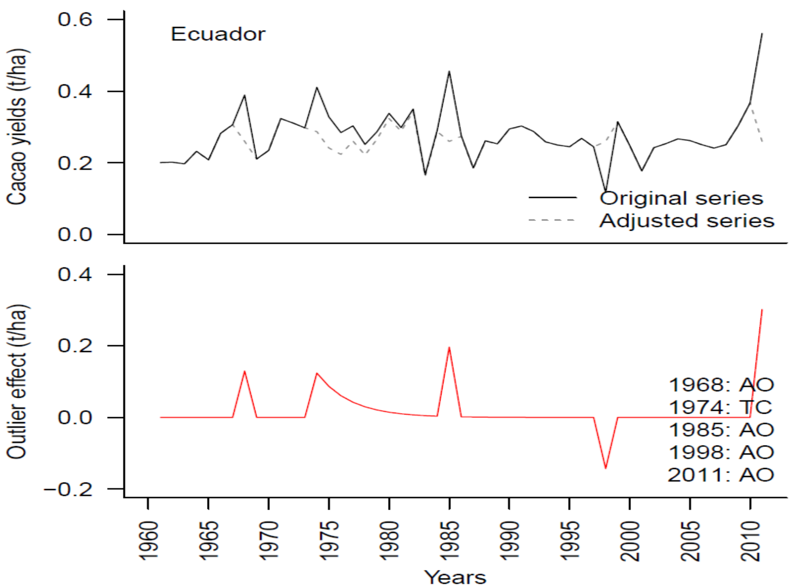

Figure 18 Outliers of the cocoa time series in Ecuador between 1960 and 2014

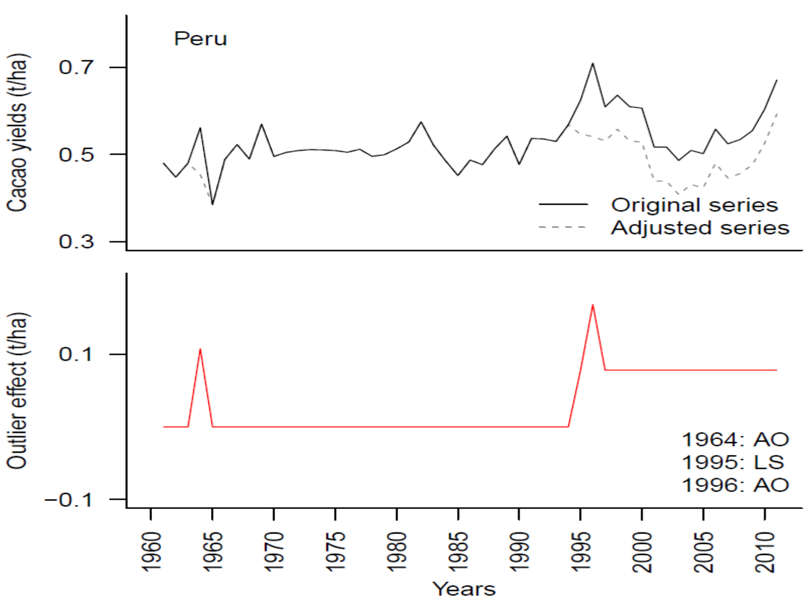

Figure 19 Outliers of the cocoa time series in Peru between 1960 and 2014

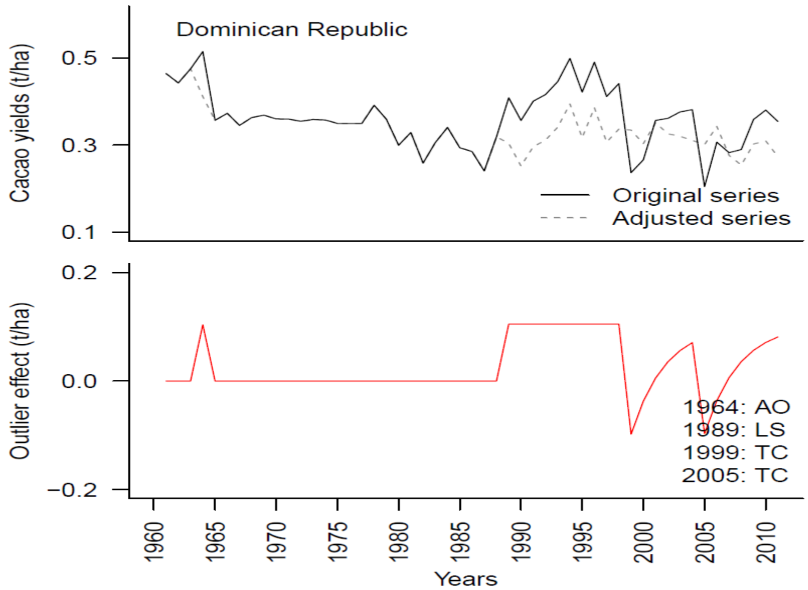

Figure 20 Outliers of the cocoa time series in Dominican Republic between 1960 and 2014

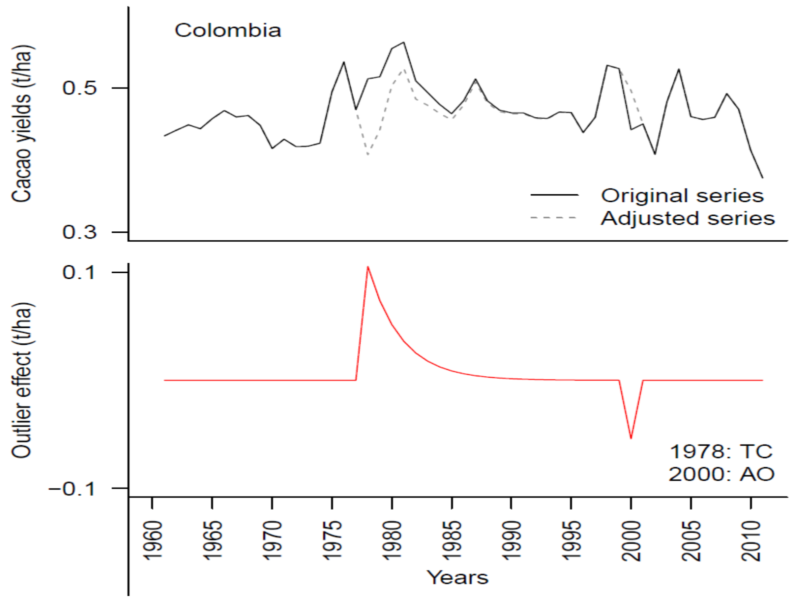

Figure 21 Outliers of the cocoa time series in Colombia between 1960 and 2014

APPENDIX B: SUMMARY OF STATISTICAL MODELS ESTIMATED

Table 13: Statistical Models for cocoa yield forecasts

Country	Statistical Model
Côte d'Ivoire	$\Delta y_t = 0.0067 - 0.8475\Delta y_{t-1} - 0.6541\Delta y_{t-2} - 0.5293\Delta y_{t-3} - 0.3957\Delta y_{t-4} + 0.0944AO_{1971} - 0.0897TC_{1982} - 0.1339LS_{2005} + \epsilon_t$
Ghana	$y_t = 0.2509 + 0.3288y_{t-1} + 0.3357y_{t-2} + 0.1243LS_{1988} + \epsilon_t$
Indonesia	$\Delta y_t = 0.2669\Delta y_{t-1} - 0.4846\Delta y_{t-2} + 0.4043AO_{1985} + 0.4403AO_{1998} + \epsilon_t$
Cameroon	$\Delta y_t = 0.0049 - 0.0860LS_{1975} - 0.0592AO_{1976} + 0.0487AO_{1995} + \epsilon_t$
Nigeria	$y_t = 0.3195 + 0.8414y_{t-1} - 0.1645AO_{1995} + \epsilon_t - 0.3733\epsilon_{t-1}$
Brazil	$\Delta y_t = -0.1331AO_{1990} + \epsilon_t - 0.4387\epsilon_{t-1} + 0.0827\epsilon_{t-2} + 0.3528\epsilon_{t-3}$
Ecuador	$y_t = 0.2595 + 0.1297AO_{1968} + 0.1239TC_{1974} + 0.1940AO_{1985} - 0.1429AO_{1998} + 0.3017AO_{2011} + \epsilon_t$
Peru	$y_t = 0.5015 + 0.1079AO_{1964} + 0.0784LS_{1995} + 0.0904AO_{1996} + \epsilon_t + 0.5880\epsilon_{t-1} + 0.6682\epsilon_{t-2} + 0.4805\epsilon_{t-3}$
Dominican Republic	$\Delta y_t = 0.1036AO_{1964} + 0.1048LS_{1989} - 0.2027TC_{1999} - 0.1775TC_{2005} + \epsilon_t - 0.5038\epsilon_{t-1}$
Colombia	$y_t = 0.4616 + 0.9249y_{t-1} - 0.7823y_{t-2} + 0.2776y_{t-3} + 0.1052TC_{1978} - 0.0542AO_{2000} + \epsilon_t$

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