A New Look at Contraceptive Prevalence Plateaus in Sub-Saharan Africa:

A Probabilistic Approach

APPENDIX A: Supplementary Methods & Results

2024

Contents

1 Supplementary Details on Methods

1.1 Determination of Rate Condition Thresholds

1.1.1 Method

To determine which rate condition thresholds to use, we analyzed the distributions of annual percentage point differences of posterior median estimates of the two indicators studied, namely modern contraceptive prevalence (MCP) and need for family planning satisfied with modern methods (also called demand for family planning satisfied with modern methods, hereafter abbreviated DS). The posterior medians came from United Nations (2022).

Specifically, if $\tilde{y}_{c,t,i}$ is the posterior median estimate of indicator i, year t, country c, we computed $\Delta_{c,t,i} = \tilde{y}_{c,t,i} - \tilde{y}_{c,t-1,i}$ for all 48 countries of interest in sub-Saharan Africa, for years in the range 1980–2020 (incl.) in which the level condition for indicator i was satisfied (see Methods section, main article). We were interested in whether the rate condition thresholds proposed by Ross et al. (2004), namely 0.1, 0.3, and 0.5 percentage points per year, identified years where change was atypically slow in the estimates used in our study.

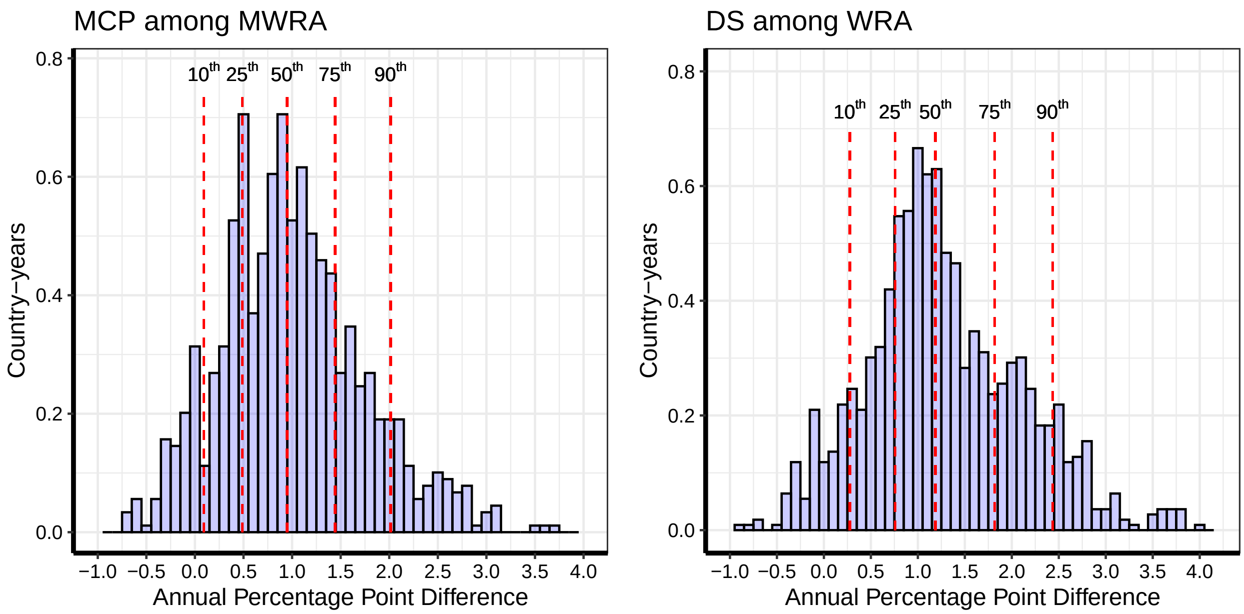
1.1.2 Results and Conclusions

The median annual difference across all countries and qualifying years 0.95 percentage points for MCP and 1.19 percentage points for DS; see Table 1.1 and Figure 1.1). The percentile ranks of the rate condition thresholds used by Ross et al. (2004) are shown in Table 1.2. These statistics give the proportions of annual differences that fall below the respective thresholds, expressed as percentages.

The rate condition thresholds of 0.1, 0.3 and 0.5 percentage points per year) appeared appropriate for identifying atypically slow changes in the estimates used in this study. The largest threshold, 0.5 percentage points, was in the bottom 26 percent for MCP and the bottom 16 percent for DS.

Table 1.1. Selected quantiles of annual percentage point differences in posterior median estimates by indicator and marital status. The results are for all 48 countries of interest in sub-Saharan Africa, for years in the range 1980–2020 (incl.). Only years that met the respective level conditions were included (see Methods section, main article). *Key:* "MCP among MWRA" = modern contraceptive prevalence (MCP) among married/in-union women of reproductive age (MWRA); "DS among WRA" = need for family planning satisfied with modern methods (DS) among women of reproductive age (WRA).

Percentile	MCP among MWRA	DS among WRA
10%	0.09	0.28
25%	0.49	0.76
50%	0.95	1.19
75%	1.44	1.82
90%	2.01	2.43



(a) Modern contracetpive prevalence (MCP) among married or in-union women of reproductive age (MWRA).

(b) Need for family planning satisfied with modern methods (DS) among women of reproductive age (WRA).

Figure 1.1. Distributions of annual percentage point differences in posterior median estimates by indicator and marital status. The results are for all 48 countries of interest in sub-Saharan Africa, for years in the range 1980–2020 (incl.). Only differences in years that met the respective level conditions were retained (see Methods section, main article). Dashed vertical lines mark the 10th, 25th, 50th (median), 75th, and 90th quantiles (see also Table 1.1). For visual clarity, observations above the upper 0.005 quantile were trimmed before plotting, but after calculating the quantiles.

Table 1.2. Percentile ranks of the thresholds 0.1, 0.3, and 0.5 in the distributions of annual percentage point differences in posterior medians by indicator and marital status. The results are for all 48 countries of interest in sub-Saharan Africa, for years in the range 1980–2020 (incl.). Only years that met the respective level conditions were included (see Methods section, main article). *Key:* "MCP among MWRA" = modern contraceptive prevalence (MCP) among married/in-union women of reproductive age (MWRA); "DS among WRA" = need for family planning satisfied with modern methods (DS) among women of reproductive age (WRA).

Threshold	MCP among MWRA	DS among WRA
0.1	10	7
0.3	15	11
0.5	26	16

1.2 Determination of the Method of Identifying Probabilistic Plateaus

1.2.1 Plateau Identification via Annual First Differences

Our initial approach to estimating the probability of a plateau based on a rate condition was to take annual first differences of each MCMC trajectory and, in each year, measure the proportion of differenced trajectory values that exceeded the threshold. In years where this proportion exceeded the probability threshold, it was declared to be a plateau year. More formally:

Annual First Difference Method: A year is a plateau year if the following conditions (1–3) are satisfied:

1. **Level condition:**
   a. *MCP:* Posterior median MCP previously exceeded 10 percent but remains below 60 percent.
   b. *DS:* Posterior median DS previously exceeded 20 but remains below 80 percent.
2. **Rate condition:** At the trajectory level, the change from the previous year is less than δ percentage points, for $\delta = 0.1, 0.3, 0.5$.
3. **Probability condition:** At least γ percent of the trajectories satisfy the rate condition, for $\gamma = 80, 90, 95$.

This method, however, was found to be ill-suited to plateau identification in MCMC trajectories which are typically highly volatile. In particular, it failed when a plateau was present but the trajectory oscillated about it with an amplitude less than the rate condition threshold. A stylized depiction of such a situation is in Figure 1.2 (a)–(d), for which a rate condition threshold of 0.5 percentage points was used. The true underlying trends in these examples were constant, so a plateau should have been identified. Indeed, when the trajectory moved about the trend with changes at or below the 0.5 percentage point threshold, the plateau was correctly identified (a), (b). However, a small increase in the amplitude of the oscillations lead to a broken series of plateaus (c), (d). The same thing happened when the underlying trend was increasing (e), (f); no plateau was present but the procedure nevertheless yielded a broken sequence of plateaus.

The examples are highly stylized; for instance, trajectories are typically auto-correlated which would produce non-uniform oscillations. Nevertheless, the potential for too many false negatives, or for such volatility to cause misidentification of plateaus via broken sequences or singleton plateaus in isolated years, is statistically undesirable. It could also lead to problems interpreting results; for example, a singleton plateau might, at first glance, suggest a sudden substantive change but, in reality, turn out to be an artefact of trajectory volatility.

Setting higher thresholds in the rate and probability conditions could alleviate the problem, but these modifications would affect plateau identification at all years, potentially leading to more being missed. An alternative could be to introduce the concept of a plateau *period*, as distinct from a plateau *year*, and require that at least two adjacent years jointly satisfy the level and rate conditions. This is conceptually preferable to a higher probability threshold as it operates locally on small sets of years rather than globally on all years. This approach could be quite conservative, however. Consider Figure 1.2 (c)–(f). Under this additional condition, none of the years would be declared a plateau as there are no plateau-year sequences of length at least two. These problems led us to consider smoothing approaches which we discuss next.

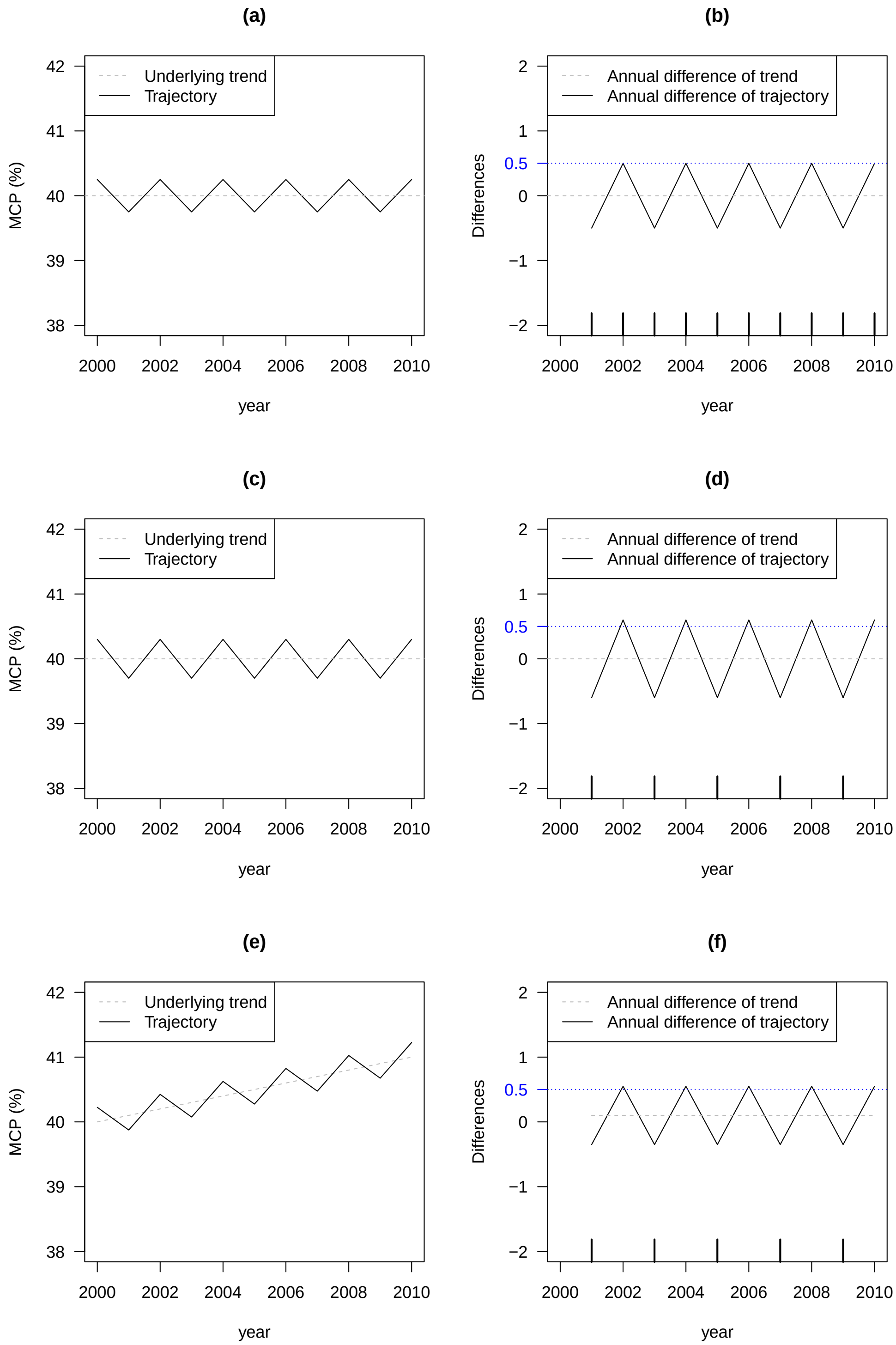


Figure 1.2. Stylized trajectories and their annual first differences. *Panels:* (a) Trajectory oscillating around the constant value 40 percent, amplitude 0.5 percentage points; (b) annual difference of (a); (c) trajectory oscillating around the constant value 40 percent, amplitude 0.6 percentage points; (d) annual difference of (c); (e) trajectory oscillating with amplitude 0.45 percentage points per year around a trend which increases at 0.1 percentage point per year; (f) annual difference of (e). Vertical lines rising from the x-axes in (b), (d), and (f) mark individual years identified as plateau years using the annual difference method with rate condition threshold $\delta = 0.5$.

1.2.2 Plateau Identification via Local Smoothing

We investigated two local smoothing methods, one based on moving averages, the other on local linear fits. Both methods required the choice of a bandwidth parameter, h, which was the width of the window over which the average or linear fit was calculated. Odd widths (e.g., 3, 5, ...) have the desirable property that they are symmetric about the year being smoothed. The minimum effective odd bandwidth, $h = 3$, was deemed suitable as an h of 5 years seemed too long to identify short-term plateaus.

Moving averages and local linear fits intrinsically take account of groups of adjacent years, so the requirement that any year be part of a period of greater length than one year was not considered. This did not rule out singleton plateau years but we expected them to be less likely than under the annual difference method.

Moving Average Smoother

Moving Average Method: A year is a plateau year if the following conditions (1–3) are satisfied:

1. **Level condition:**
   a. *MCP:* Posterior median MCP previously exceeded 10 percent but remains below 60 percent.
   b. *DS:* Posterior median DS previously exceeded 20 but remains below 80 percent.
2. **Rate condition:** The change in the moving average of the current year, relative to the moving average in the previous year, is less than δ percentage points, for $\delta = 0.1, 0.3, 0.5$.
   - To obtain the moving averages, take moving averages of width $h = 3$ years, centred at the current year.
3. **Probability condition:** At least γ percent of the trajectories satisfy the rate condition, for $\gamma = 80, 90, 95$.

Applying the moving average smoother to the scenarios shown in Figure 1.2 (c)–(f) produced the results in Figure 1.3. The moving averages (Panels (a) and (c)) clearly smoothed out the original trajectories. As a result, the annual differences were smaller and fell below the 0.5 percent threshold, yielding an unbroken sequence of plateaus (Panels (b) and (d)).

Local Linear Smoothing

The local linear smoothing definition of a contraceptive transition plateau is as follows:

local linear smoothing method: A year is a plateau year if the following conditions (1–3) are satisfied:

1. **Level condition:**
   a. *MCP:* Posterior median MCP previously exceeded 10 percent but remains below 60 percent.
   b. *DS:* Posterior median DS previously exceeded 20 but remains below 80 percent.
2. **Rate condition:** The slope coefficient of a locally fitted ordinary least squares (OLS) regression is less than δ percentage points, for $\delta = 0.1, 0.3, 0.5$.
   - To obtain the slope coefficient, fit an ordinary least squares (OLS) regression to the trajectory values of years in a window of width $h = 3$ years, centred at the current year. Store only the slope coefficient.

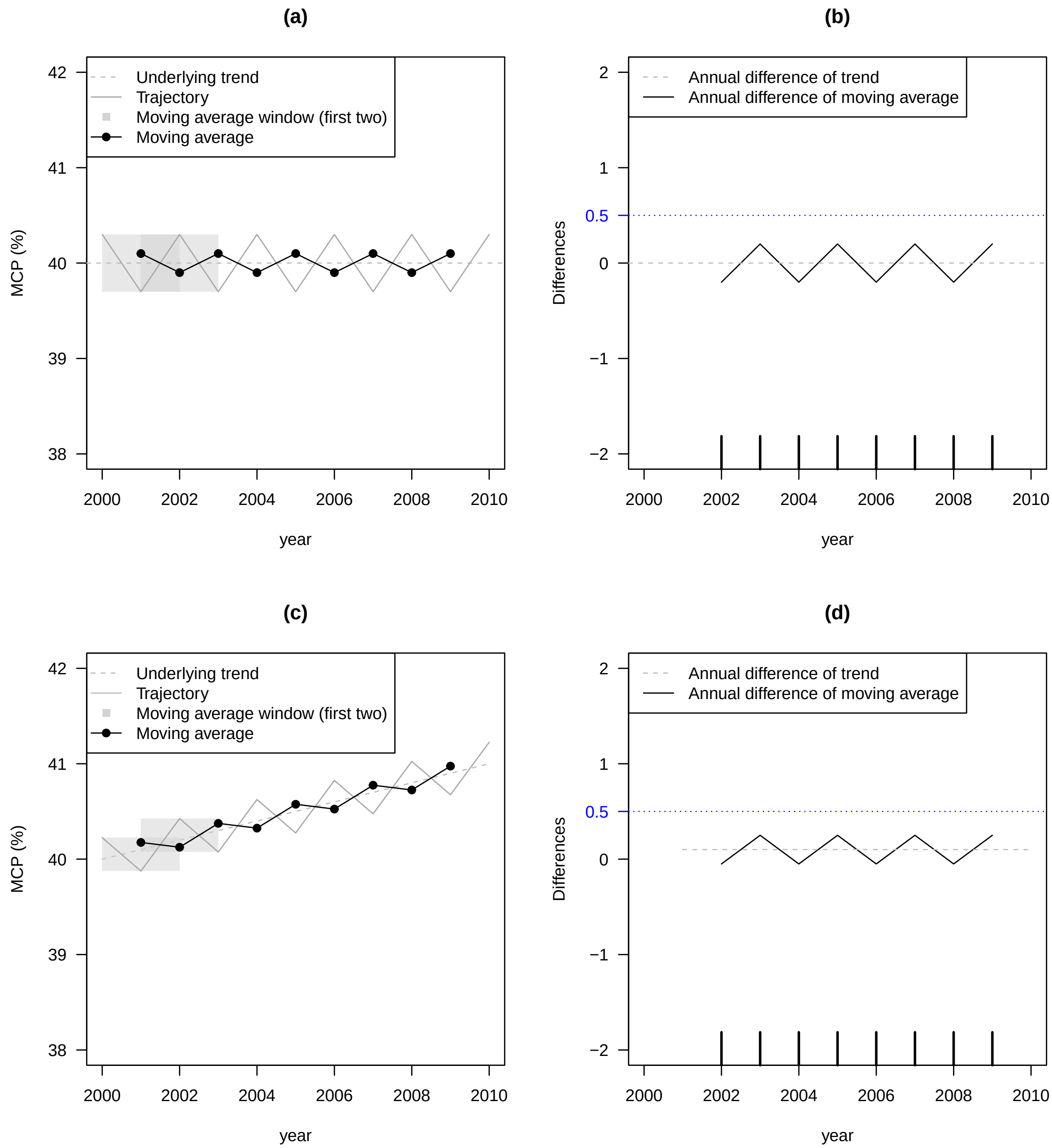


Figure 1.3. Stylized trajectories and their moving averages. *Panels:* (a) moving average, bandwidth $h = 3$, of trajectory oscillating around the constant value 40 percent, amplitude 0.5 percentage points; (b) annual difference of (a); (c) moving average, bandwidth $h = 3$, of trajectory oscillating with amplitude 0.45 percentage points per year around a trend which increases at 0.1 percentage point per year; (d) annual difference of (c). Grey squares in (a) and (c) indicate the 3-year windows over which the moving averages were calculated (only two windows are shown for illustration). Vertical lines rising from the x-axes in (b) and (d) mark individual years identified as plateau years using the moving average method with rate condition threshold $\delta = 0.5$.

3. **Probability condition:** At least γ percent of the trajectories satisfy the rate condition, for $\gamma = 80, 90, 95$.

The local linear smoothing method is illustrated in Figure 1.4. Panels (a) and (c) repeat the scenarios from Figure 1.3. The solid circles are the fitted values from simple linear regressions fitted to the sample trajectory. The dashed lines are the linear regression lines from a sequence of linear regressions independently fitted to the trajectory values inside three-year moving windows centered at each year (illustrated by the grey squares).

The slope coefficients are shown as dashed lines in Panels (a) and (c), and crosses in Panels (b) and (d). The underlying trends satisfied the annual change criterion of 0.5 percentage points, therefore all years were identified as plateaus.

Example Application to Real Trajectories

The application of each of method of plateau identification to actual *FPEMglobal* trajectories for Cameroon is shown in Figures 1.5 and 1.6 for MCP and DS, respectively. No plateau years were identified under the annual difference method. Plateaus in MCP were found in 2016 and 2017 by the moving average method, and in 2015 and 2016 by the local linear smoothing method.

1.2.3 Comparison of Smoothing Methods

The moving average and local linear smoothing methods reduce sensitivity to short-term volatility relative to the annual difference method. However, the moving average method does so only up to a point. If the amplitude of the trajectory volatility is too great, false negatives and broken sequences of plateaus can still occur. With a rate condition threshold of 0.5 percentage points, annual changes of 2 percentage points are enough to cause this kind of failure in our stylized experiment (Figure 1.7 (a), (b)). In contrast, the local linear smoother is not affected by the oscillation amplitude (panels (c), (d)).

In both stylized applications of the local linear smoothing method shown in Figure 1.4 the slope coefficients matched exactly the value of the underlying trend; 0 in panels (a) and (b), 0.1 in panels (c) and (d). This was to be expected since the underlying trends in both cases were, themselves, simple linear trends and the local regressions provided unbiased estimates of them. In general, the underlying trend will not be linear but, over the short span of the three-year windows, it was reasoned that the regression coefficients would be useful summaries of the local rates of change, remain robust enough to smooth out the volatility of the MCMC trajectories but still be sensitive to real plateaus of meaningful length. Therefore, the local linear smoothing method was selected as the preferred method for the full analysis reported in the main article.

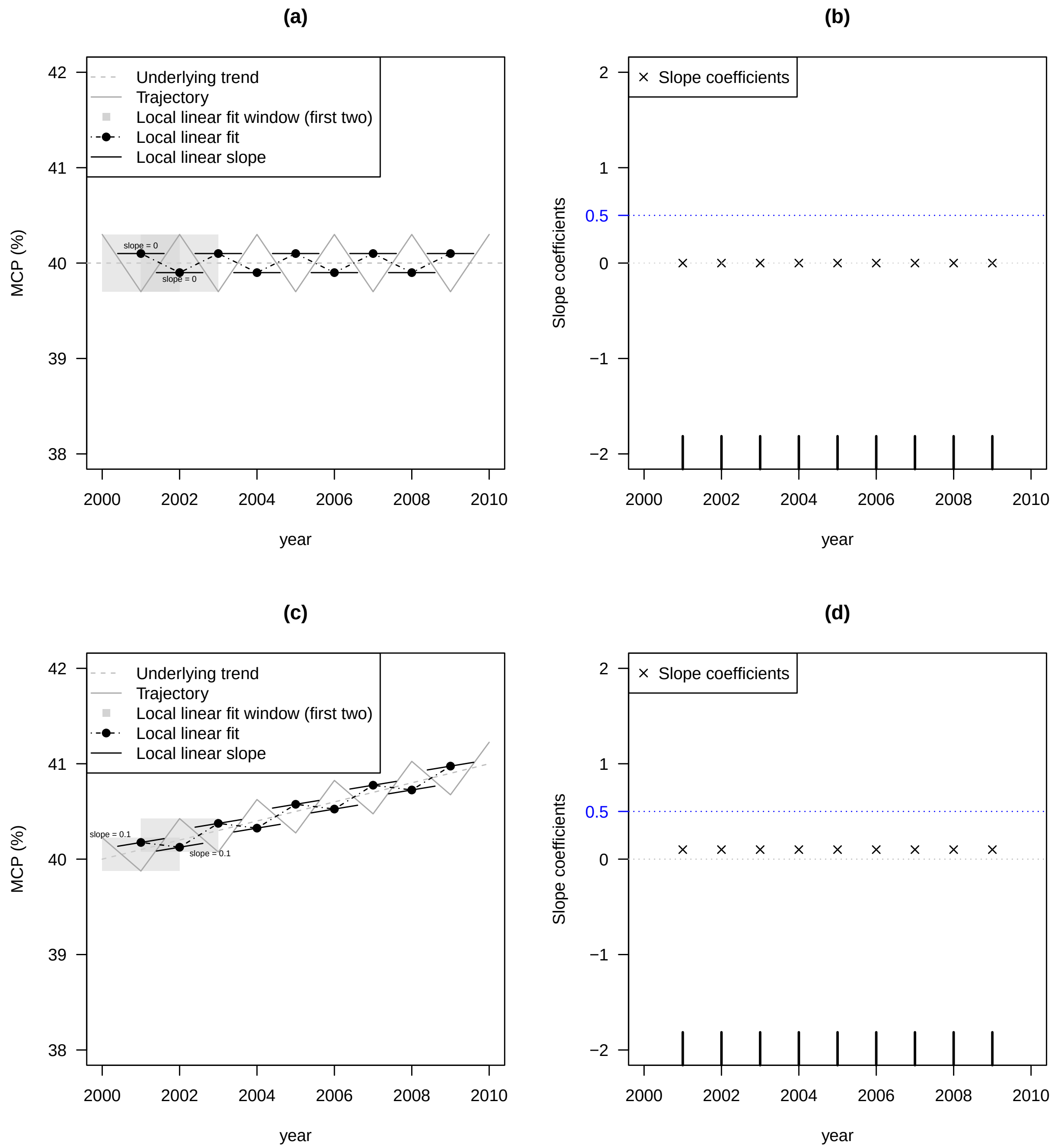


Figure 1.4. Stylized trajectories and their local linear smooths. *Panels:* oscillating around a constant and a trend. (a) local linear fits, bandwidth $h = 3$, of trajectory oscillating around the constant value 40 percent, amplitude 0.5 percentage points; (b) slope coefficients from (a). (c) Local linear fits, bandwidth $h = 3$, of trajectory oscillating with amplitude 0.45 percentage points per year around a trend which increases at 0.1 percentage point per year; (d) slope coefficients from (c). In (a) and (c), the grey squares indicate the 3-year windows (only two are shown for illustration). Vertical lines rising from the x-axes in (b) and (d) mark individual years identified as plateau years using the Local Linear Smoother Method with rate condition threshold $\delta = 0.5$.

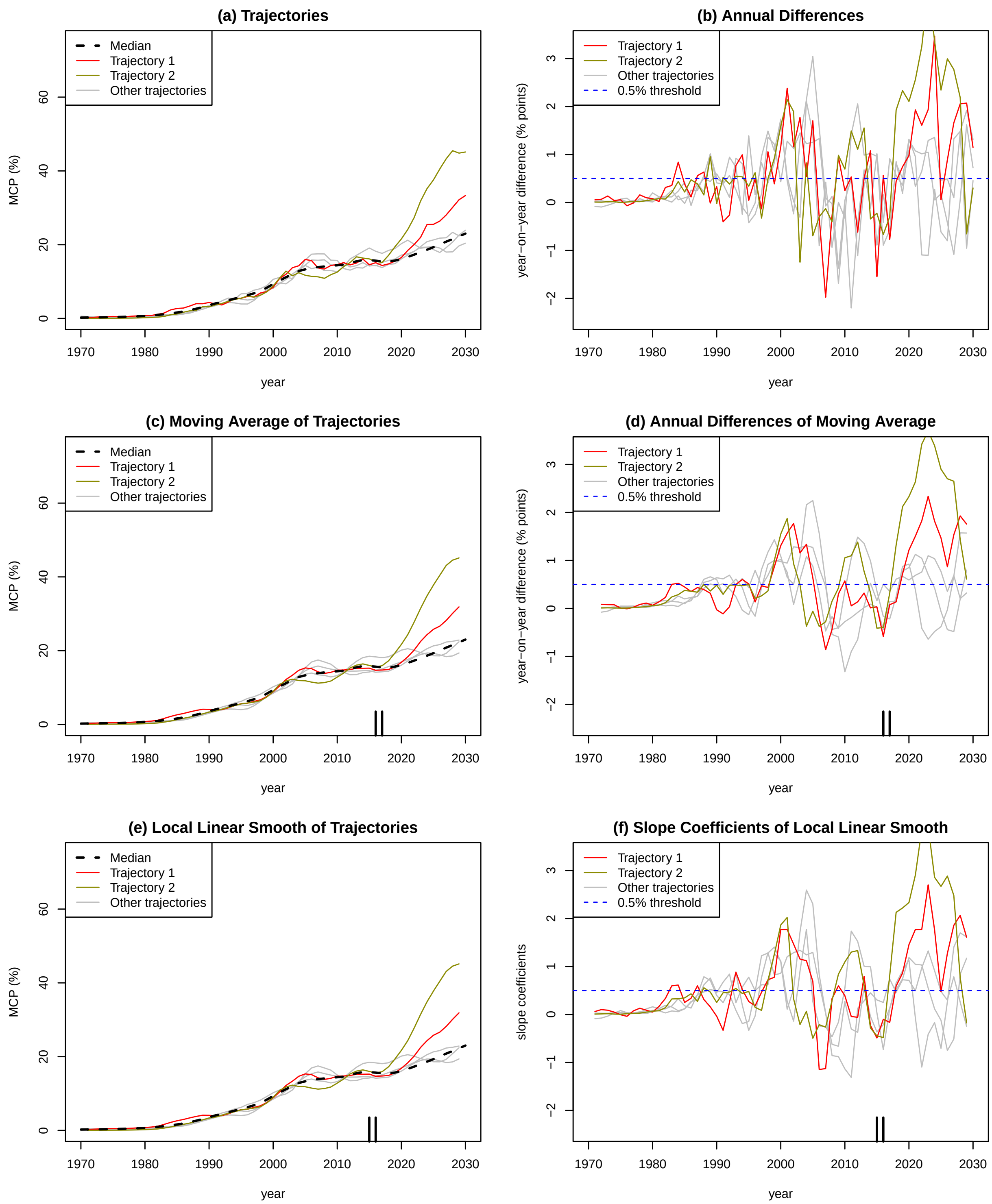


Figure 1.5. Model-based estimates, selected trajectories, and plateau analysis of modern contraceptive prevalence (MCP) among married/in-union women of reproductive age (MWRA) for Cameroon. *Panels:* (a) sample trajectories of MCP; (b) annual difference of trajectories in (a); (c) moving averages of sample trajectories; (d) annual difference of moving averages in (c); fitted values from local linear smooths; (f) slope ceofficients of the local linear smooths in (e). Any vertical lines rising from the x-axes mark years identified as plateau years based on all trajectories, for rate condition threshold $\delta = 0.5$, probability condition threshold $\gamma = 80$, bandwidth $h = 3$.

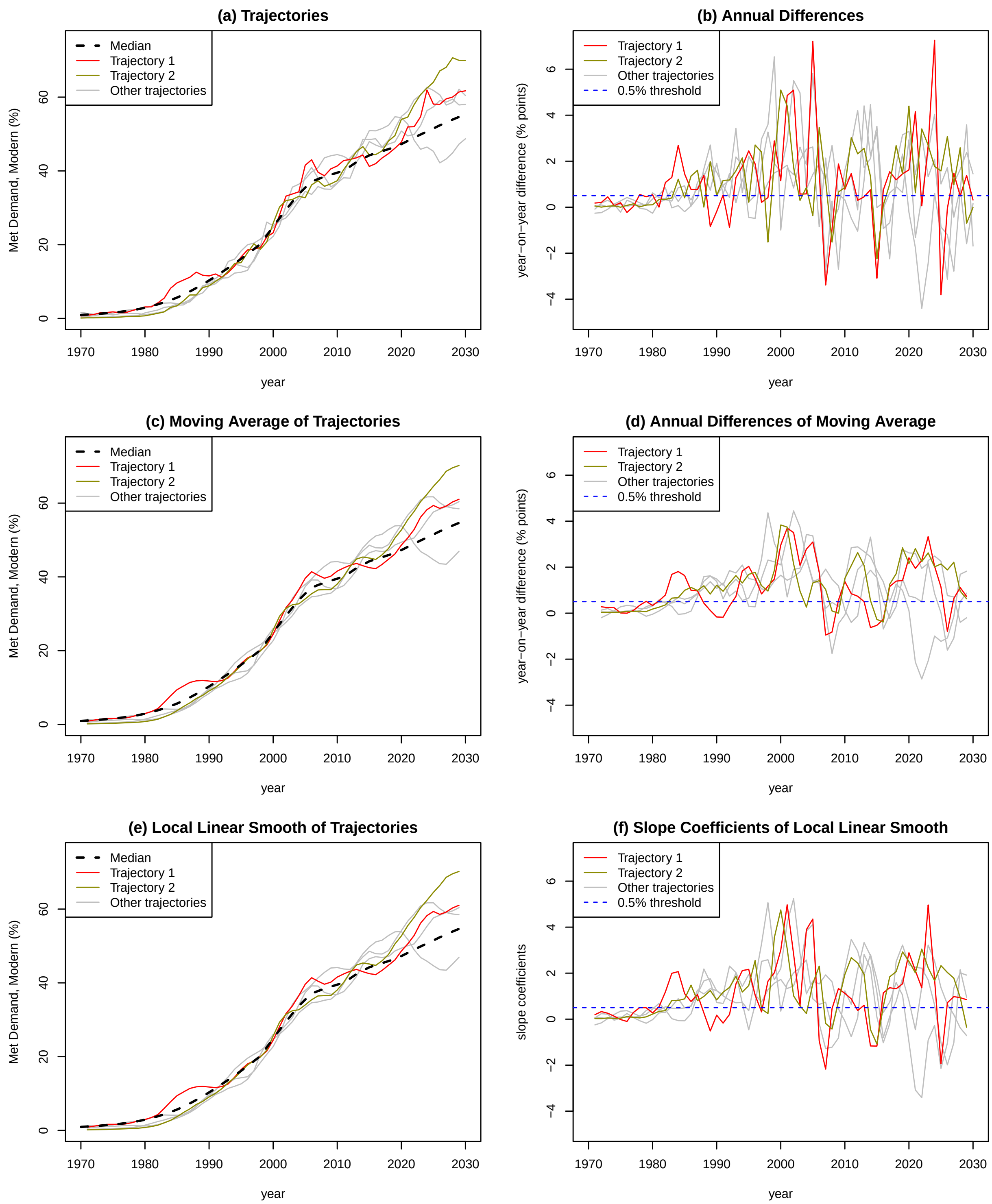


Figure 1.6. Model-based estimates, selected trajectories, and plateau analysis of need for family planning satisfied with modern methods (DS) among all women of reproductive age (WRA) for Cameroon. *Panels:* (a) sample trajectories of DS; (b) annual difference of trajectories in (a); (c) moving averages of sample trajectories; (d) annual difference of moving averages in (c); fitted values from local linear smooths; (f) slope ceofficients of the local linear smooths in (e). Any vertical lines rising from the x-axes mark years identified as plateau years based on all trajectories, for rate condition threshold $\delta = 0.5$, probability condition threshold $\gamma = 80$, bandwidth $h = 3$.

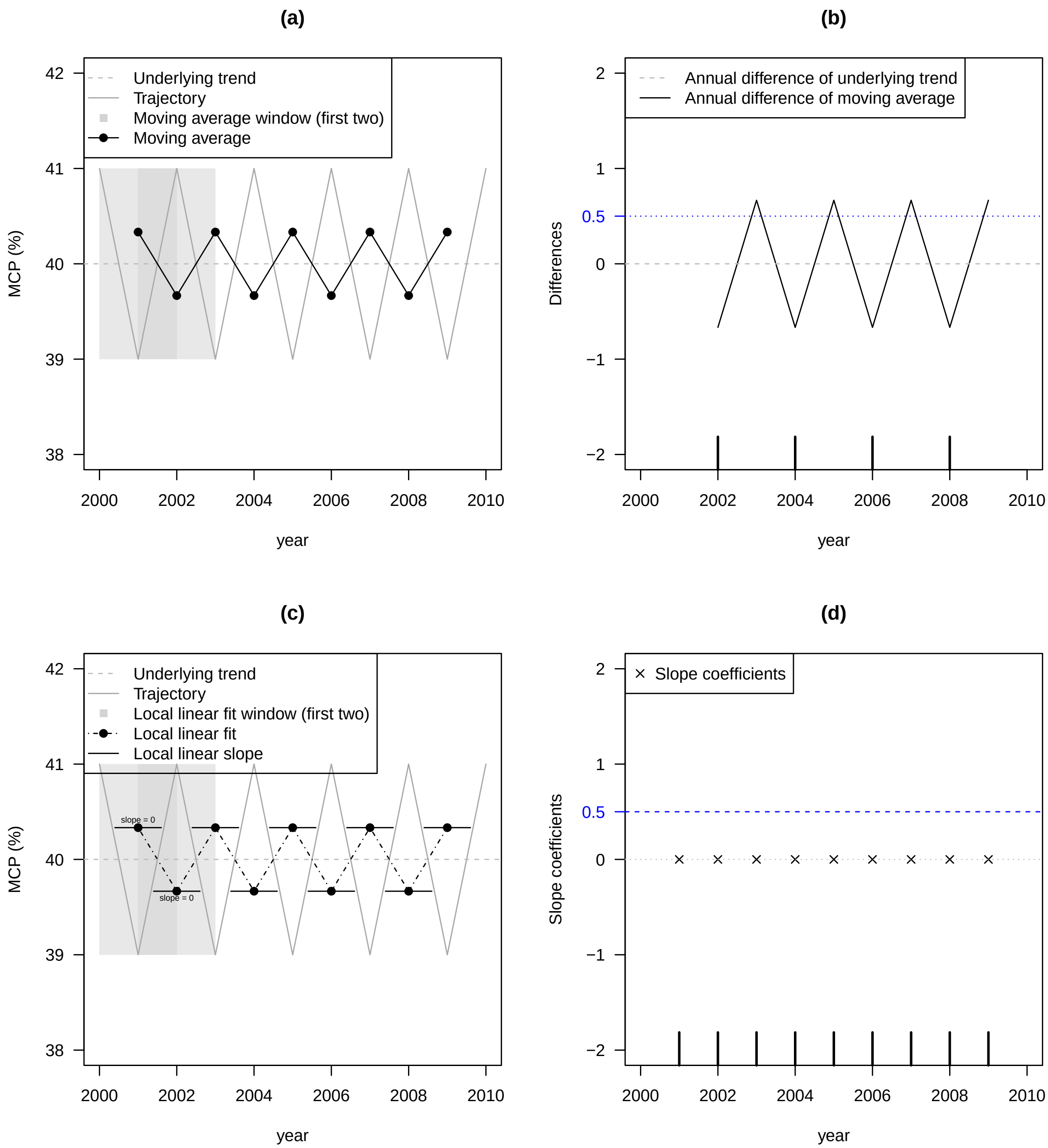


Figure 1.7. Stylized trajectories, moving averages and local linear smooths. *Panels:* (a) moving average, bandwidth $h = 3$, of trajectory oscillating around the constant value 40 percent, amplitude 2 percentage points; (b) annual difference of (a); (c) local linear fits, bandwidth $h = 3$, of the same trajectory from (a); (d) slope coefficents from (c). Vertical lines rising from the x-axes in (b) and (d) mark individual years identified as plateau years using the moving average method (panel (b)), and local linear smoothing method (panel (d)), both with rate condition threshold $\delta = 0.5$.

2 Supplementary Results

For the interested reader, Section 2.1 provides summaries of the plateaus identified under each of the three methods of plateau identification studied in Section 1.2 under all nine combinations of rate and probability thresholds. Supplementary commentary on the effects of varying the condition thresholds of the local linear smoothing method is given in Section 2.2 (see also Appendix B, Section 2). Finally, Section 2.3 provides supplementary results on the comparison of MCP plateaus and fertility transition stalls.

2.1 Comparison of Results Across Methods of Plateau Identification and Thresholds

Table 2.1. Contraceptive prevalence plateaus using the annual difference method. Total number of contraceptive prevalence plateau years identified, by country, in modern contraceptive prevalence (MCP) among married/in-union women of reproductive age (MWRA), for all combinations of rate and probability condition thresholds, using the annual difference method. Countries are grouped by subregion, which appear in alphabetical order; countries appear alphabetically within subregion. *NOTE:* No DS plateaus were identified using the annual difference method.

				Rate condition threshold								
				0.5			0.3			0.1		
				Probability			Probability			Probability		
Marital Group	Indicator	Subregion	Country	80	90	95	80	90	95	80	90	95
MWRA	MCP	Eastern Africa	Mozambique	3								
			Rwanda	8	6	2	8	4		5	1	
		Western Africa	Gambia	10	6		8					
			Ghana	2								
			Mauritania	2								
			Niger	2	1		2					
			Nigeria	1								
		TOTAL		*28*	*13*	*2*	*18*	*4*		*5*	*1*	

Table 2.2. Contraceptive prevalence plateaus using the moving average method. Total number of contraceptive prevalence plateau years identified, by country, in modern contraceptive prevalence (MCP) among married/in-union women of reproductive age (MWRA) and need for family planning met with modern methods (DS) among all women of reproductive age (WRA), for all combinations of rate and probability condition thresholds, using the moving average method. Countries are grouped by subregion, which appear in alphabetical order; countries appear alphabetically within subregion.

				Rate condition threshold								
				0.5			0.3			0.1		
				Probability			Probability			Probability		
Marital Group	Indicator	Subregion	Country	80	90	95	80	90	95	80	90	95
MWRA	MCP	Eastern Africa	Burundi	1								
			Comoros	7								
			Mozambique	4	2		1					
			Rwanda	8	7	6	7	6	6	6	6	5
		Middle Africa	Cameroon	2								
		Southern Africa	South Africa	6			4					
		Western Africa	Gambia	10	9	8	9	7		7		
			Ghana	3	2		2					
			Mauritania	4								
			Niger	4	3	2	3	2		2		
			Nigeria	3	2		1					
		TOTAL		*52*	*25*	*16*	*27*	*15*	*6*	*15*	*6*	*5*
WRA	DS	Western Africa	Gambia	6								
			Ghana	3								
			Niger	2			2			1		
			Nigeria	3	1		1					
		TOTAL		*14*	*1*		*3*			*1*		

Table 2.3. Contraceptive prevalence plateaus using the local linear smoothing method. Total number of contraceptive prevalence plateau years identified, by country, in modern contraceptive prevalence (MCP) among married/in-union women of reproductive age (MWRA) and need for family planning met with modern methods (DS) among all women of reproductive age (WRA), for all combinations of rate and probability condition thresholds, using the local linear smoothing method. Countries are grouped by subregion, which appear in alphabetical order; countries appear alphabetically within subregion.

				Rate condition threshold								
				0.5			0.3			0.1		
				Probability			Probability			Probability		
Marital Group	Indicator	Subregion	Country	80	90	95	80	90	95	80	90	95
MWRA	MCP	Eastern Africa	Comoros	1								
			Mozambique	3								
			Rwanda	8	7	7	7	7	6	7	5	2
		Middle Africa	Cameroon	2								
		Southern Africa	South Africa	5								
		Western Africa	Gambia	11	8	5	9	4		5		
			Ghana	3			1					
			Mauritania	3								
			Niger	3	2	1	2	1		1		
			Nigeria	3	1		1					
		TOTAL		*42*	*18*	*13*	*20*	*12*	*6*	*13*	*5*	*2*
WRA	DS	Western Africa	Niger	2			1					
			Nigeria	2								
		TOTAL		*4*			*1*					

2.2 Sensitivity to Plateau Condition Thresholds

2.2.1 Level Condition Thresholds

The level condition had the expected effect of precluding many periods of no, or very slow, increase from being declared plateaus. Under the rate condition threshold of 0.5 percentage points, the probability of an MCP plateau exceeded 80 percent in 530 country-years, but in 488 (92 percent) of these the level condition failed. Similarly, for DS, plateau probability exceeded 80 percent in 70 country-years but the level condition failed in 66 (94 percent) of them.

In Rwanda, Gambia, and Nigeria, MCP fell back below the lower threshold of 10 percent, having previously exceeded it, resulting in plateaus at MCPs below 10 percent. In South Africa, MCP exceeded the upper threshold of 80 percent but subsequently dipped back below it, causing the onset of a plateau there.

2.2.2 Rate and Probability Condition Thresholds

Using stricter rate and probability condition thresholds resulted in fewer and shorter plateaus (Table 2.3). The only plateau identified under the most stringent thresholds was the MCP plateau in Rwanda. The part covering 1994–1995 was identified with probability 95 percent under a rate condition threshold of 0.1 percentage points. The plateaus in Gambia and Niger were also persistently identified, both with probably 90 percent under a rate condition threshold of 0.3 and with 80 percent under a threshold of 0.1. In all three cases, the lengths of the plateaus reduced as the thresholds tightened.

For DS, the plateau in Niger persisted for a single year with probability 80 percent at a reduced rate condition threshold of 0.3. All other modifications resulted in no plateau years for this indicator.

2.3 MCP Plateaus and Fertility Transition Stalls

The full tabulation of MCP plateau and fertility transition stall years (Schoumaker, 2019), by country, is shown in Table 2.4. Only countries with either a plateau, a stall, or both are shown. MCP plateaus and fertility transition stalls are displayed for all countries studied in Appendix B, Section 1.

The cross-classification of countries by the occurrence of at least one plateau or stall is in Table 2.5. Countries with multiple fertility transition stalls were counted only once. This table was used to calculate the ratio of the odds of having a stall to the odds of having a plateau. It is the basis of the odds-ratio analysis in the Results section of the main article.

Table 2.4. Contraceptive prevalence plateaus and fertility transition stalls. Time periods in which modern contraceptive prevalence (MCP) plateaus and fertility transition stalls occurred by strength of evidence identified by Schoumaker (2019) among married/in-union women of reproductive age (MWRA), for countries in sub-Saharan Africa with at least one plateau or stall. For contraceptive transition stalls, the change condition threshold was 0.5 and the probability condition threshold was 80 percent. Countries are grouped by subregion, which appear in alphabetical order; countries appear alphabetically within subregion.

Subregion	Country / Area	Years	No. Years	MCP plateau	TFR stall
Eastern Africa	Comoros	2007	1	Yes	
	Kenya	1993–1997	5		Limited evidence
		1998–2013	16		Strong+ evidence
	Madagascar	1992–1997	6		Moderate evidence
	Malawi	2000–2003	4		Limited evidence
	Mozambique	2007–2009	3	Yes	
	Rwanda	1993–1999	7	Yes	
		2000	1	Yes	Limited evidence
		2001–2004	4		Limited evidence
	Uganda	2001–2005	5		Limited evidence
	United Republic of Tanzania	1999–2004	6		Moderate evidence
	Zambia	1992	1		Limited evidence
		1993–1995	3		Limited evidence
		2002–2007	6		Strong+ evidence
	Zimbabwe	2005–2011	7		Strong+ evidence
		2012–2015	4		Strong+ evidence
Middle Africa	Cameroon	1998–2000	3		Strong+ evidence
		2001–2004	4		Strong+ evidence
		2005–2010	6		Limited evidence
		2015–2016	2	Yes	
	Congo	2005–2011	7		Strong+ evidence
	Gabon	2000–2012	13		Moderate evidence
Southern Africa	Namibia	2007–2013	7		Strong+ evidence
	South Africa	1998–2001	4		Moderate evidence
		2002–2008	7		Moderate evidence

		2009–2013	5	Yes	Moderate evidence
		2014–2016	3		Moderate evidence
Western Africa	Benin	2001–2005	5		Limited evidence
	Burkina Faso	1993–1998	6		Limited evidence
	Côte d'Ivoire	1999–2005	7		Moderate evidence
		2006–2012	7		Moderate evidence
	Gambia	2002–2012	11	Yes	
	Ghana	1988–1992	5		Limited evidence
		1998–2002	5		Limited evidence
		2004–2006	3	Yes	
	Mauritania	2016–2018	3	Yes	
	Niger	2017–2019	3	Yes	
	Nigeria	1990–2003	14		Moderate evidence
		2010–2012	3	Yes	
	Senegal	1993–1996	4		Limited evidence
		2005–2010	6		Limited evidence

Table 2.5. Contingency table of countries classified by presence of modern contraceptive prevalence (MCP) plateaus and fertility transition stalls.

		Fertility		
MCP		Stall	No stall	Total
Plateau	n	5	5	*10*
	(%)	(10.4)	(10.4)	*(20.8)*
No plateau	n	14	24	*38*
	(%)	(29.2)	(50)	*(79.2)*
Total	n	19	29	*48*
	(%)	*(39.6)*	*(60.4)*	(100)

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