Applied Geography 39 (2013) 78–92

Contents lists available at SciVerse ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

Mexican maize production: Evolving organizational and spatial structures since 1980

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Keywords:
Mexican maize production
Mexican agricultural policy
Regional and sectoral policy adjustment
Agriculture and climate risk
Commercial and traditional maize production

A B S T R A C T

Maize has long been one of the most important crops produced in Mexico. The importance of maize stems not only from its role in national economic output, but also because of its strong connections to Mexican culture and, especially, the key role it plays in supporting rural livelihoods. The past 15 years have witnessed dramatic institutional and economic changes that are impacting maize production. Some are well known, such as increasing market integration under NAFTA, while others are less well known, such as the changes in irrigated land use. After an overview of the key changes that impact maize consumption and production since 1980, we provide a detailed description of changes both to the structure of production and to the spatial organization of this production. We close with a discussion of the interplay of changes to production and consumption and the associated changes in livelihood risk, food security, and political security.

Introduction

The economic, political, and cultural importance of maize (corn) is fundamental to understanding Mexico's history. Maize is endemic to the region, and was deeply embedded in indigenous cultures long before Mexico emerged as a nation-state. In the modern era, a complex web of agricultural and social development policies afforded maize a unique, and usually highly protected status. The period from 1980 to present has witnessed a dramatic policy swing from protectionism with widespread government intervention toward deregulation and international market integration. The goal of this paper is to describe the organizational and spatial changes in maize production during that period, to interpret the timing of major shifts with respect to policies, and to discuss the implications of those changes in terms of the national food system, regional political economy, and rural livelihood strategies.

A rich literature exists that charts the national trends in maize production, the complex and changing policy nexus targeting maize production and consumption, and the cultural and economic roles of maize in rural livelihoods.[1] Our paper contributes to that literature in several ways. While the scope of our results is national, we isolate features of the recent evolution of maize production at spatial scales ranging from rural districts to national. We establish that the recent dramatic shifts in the spatial pattern of production are driven by different segments of maize producers – modern versus traditional. Finally, while the patterns suggest that the modern sector is rapidly learning and adopting new production technologies, the traditional sector continues to persist. All of these findings are meaningful because they reflect overt changes in national policy with differential regional impacts and imply different exposures to environmental and economic risks in the Mexican maize system. While the paper focuses specifically on Mexican agriculture and policy, the spatial and organizational adjustments we document could highlight important characteristics of domestic agriculture in countries that are embracing open market changes.

The paper proceeds as follows. Section 2 provides a brief overview of agricultural and social policies related to maize, and argues that these can be roughly grouped into five policy eras since 1980.

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[1] A partial list of foundational and recent references is Appendini and Liverman (1994), Appendini (2001, 1990), Collier (1994), de Janvry, Sadoulet, et al. (1995), Eakin (2006), Fox (1993), Fox and Haight (2010), Keleman (2010), Nadal (1999), Cornelius and Myhre (1998) and Yates (1981).

0143-6228/$ – see front matter
http://dx.doi.org/10.1016/j.apgeog.2012.12.005

The empirical findings are presented in section 3. The findings begin with broad national trends and then deconstruct those into relevant spatial patterns that are specific to season and method of production. The paper ends with a discussion of possible drivers of the emergent regional and sectoral patterns and implied risks.

Policy context of maize production

Mexican agricultural and development policies have been a major force of change within the production system but they are only weakly exogenous. Similar to other countries with large farm sectors, there are strong feedback mechanisms and interdependencies between agribusiness groups, organizational coalitions supporting the rural poor, and the federal government. In Mexico, agricultural policies have been highly reactive to spikes in social unrest tied to populist movements and constraints imposed by the global economy. Thus even though the policy context is endogenous, it is an essential framework needed to understand changes in maize production since 1980. A natural division of policy history is by presidential office: Portillo (1976–82), de la Madrid (1982–88), Salinas (1988–1994), Zedillo (1994–00), Fox (2000–06), and Calderón (2006–2012). The *sexenio* is useful because it provides uniform six year divisions and historically each new administration tended to institute new policy initiatives to deliver on campaign promises. For agricultural policy, and the effects on maize in particular, it is easier to focus on three broad policy directions: 1) *protectionist/nationalist*– Portillo and the first years of Madrid, 2) *economic liberalization* – started under Madrid and continued through Fox, and 3) *tortilla crisis response* – Calderón.

Before turning to specific policies it is necessary to provide some development policy history. As noted by Bailey (1981, p. 358), "…the legacies of previous development policies shape the current reality, as governments must 'undo' or somehow remedy the situations they inherit." The major legacy facing policy-makers even today is the existence of a large sector of poor, small-holder maize producers that have historically relied on labor-intensive production methods. That population has deep roots dating to land redistribution commencing after the Mexican Revolution and throughout the 1930s; the redistribution culminated in the *ejido*[2] form of social and agricultural organization. Early attempts to modernize and increase the productive efficiency of the *ejido* sectors failed. In response, from 1940 to the mid-1960s the government developed a dual-track policy (Gates, 1988; Yúnez-Naude & Paredes, 2006). One track involved heavy investment in irrigation and support for modernization of commercial agriculture in the Northwest and Centerwest.[3] The other track used government transfers to support the *ejido* and small-holder sector (Sanderson, 1986; Yates, 1981). Some authors have suggested that the productive inefficiency of the latter sector was accepted as the part of the cost of social control.[4] The key point for this paper, is that the dual sectors in Mexican agriculture and irrigation investments have deeper roots than the period we are analyzing. Those deep roots fostered regionally-specific cultures of modern, commercial agriculture in the Northwest, Northeast, and Centerwest.

The study period starts during the waning years of a decade's long commitment to small-holder rain-fed farmers who where predominantly located in the central and southern regions of Mexico. In 1980, the Portillo administration announced policies that were simultaneously protectionist (indefinitely delayed entry into the General Agreement on Tariffs and Trade (GATT) and restricted petroleum production) and nationalist (defined the goal of food self-sufficiency and multiple mechanisms of support for domestic production of food staples). The new support[5] for maize specifically targeted rain-fed, small-holder producers and established price guarantees, credit, and crop failure insurance that shielded small producers from the major sources of economic and climate risk. Those programs were implemented through myriad state agencies; most important were CONASUPO[6] – coordinated purchasing (domestic and imports), storing, and marketing of eleven staple crops – and BANRURAL – provided loans and crop insurance. CONASUPO's roll in the agricultural market was pervasive as it intervened and regulated every aspect of the maize commodity chain (Appendini, 2008; Yúnez-Naude, 2003). The costs of those social guarantees were underwritten by oil wealth, and were thus fundamentally unsustainable. In conjunction with the support for small farmers, the dual-track continued in the form of ongoing implementation of open markets that catered to large scale commercial agriculture (Gates, 1988).

Economic liberalization of agriculture and development policies started in the late 1980s and then accelerated during the 1990s. The de la Madrid administration was initially committed to the Portillo policies, even after Mexico defaulted on its loans in 1982. By 1985 the fiscal crisis had deepened, the IMF and World Bank became its primary creditors, and austerity measures were imposed. The de la Madrid administration started on a path toward economic liberalization – both domestically and internationally. Mexico joined the GATT in 1986 and started aggressively divesting from state run agencies and companies.

The Salinas and Zedillo administrations embraced open market reforms that transformed agricultural institutions and policies. From 1991 to 1999 CONASUPO was dismantled, and during the same period a new Government Marketing Agency (ASERCA) was established to administer a more limited set of open market policies. Guaranteed producer prices were eliminated in 1991 for all staples crops, except for maize and beans that maintained guarantees until 1999. Even with price guarantees, CONASUPO's maize market interventions declined over the period; in 1993–4 the agency purchased 36% of domestic maize production and by 1997–8 only 13% of production (Yúnez-Naude, 2003). While ASERCA continued to intervene in the market in the form of *indifference prices*,[7] market price supports decreased and prices were linked more directly to international markets (Yúnez-Naude, 2003). Other open market changes included Agrarian Law reform[8] (1992), privatization of rural credit and the elimination of BANRURAL (1990–2003), and entering into the North American Free Trade Agreement (1994). Agricultural agreements in NAFTA initially afforded maize a protected status. While markets for most agricultural products were liberalized, maize was protected by tariff rate quotas (TRQs) until 2008. However, the Zedillo administration chose not to

[2] This is a form of communal farm with members having usufruct rights. This means the land ownership is held by the community but individuals are permitted to use the land as long as they do not degrade its value.

[3] Irrigation projects specifically targeted Sinaloa and the Bahio region in Guanejuato, Queretaro, and Michoccan.

[4] For example, Gates (1988, p. 279) comments: "In general, the *ejido* can be seen as a holding device or tranquilizing factor, which provides minimal subsistence for a large sector of the rural population and serves therefore to defuse social tensions." Similar perspectives are offered by de Janvry (1975) and Bartra (1974).

[5] Sistema Alimentario Mexicano.

[6] the National Company of Popular Subsistence. For details of the agency's activities and subsidiaries see Yúnez-Naude (2003).

[7] ASERCA set region-specific "indifference" prices prior to each season that reflected transportation costs and international prices. After harvest, farmers sold their crops to processors at the prevailing international price. If the international price was lower than the indifference price then the government paid farmers the difference.

[8] The reforms made it possible to gain title to *ejido* land and provided a legitimate means of renting land (to permit more efficient commercial farmers to work the land).

impose tariffs, even when maize imports substantially exceeded quotas (Yúnez-Naude, 2003).

By the time Fox took office in 2000, the open market reforms were essentially complete. The government continued to support agriculture, and maize in particular, but used mechanisms that were broadly consistent with NAFTA and the WTO. The majority of reforms during the economic liberalization period tended to favor commercial farmers and grain processing industries over smallholder farmers (Appendini, 2011). The neglect of the smallholder sector contributed to growing discontent with Fox administration agricultural policies soon after his inauguration, eventually resulting in a new policy titled National Accord for the Countryside in 2003. While this accord diffused political tensions around agricultural policy, very little real changes occurred in programming and resource allocation. PROCAMPO, a direct payment program that began in 1994 to aid farmers transition to a free-market economy, continued under Fox, although beneficiaries are both smaller-scale and large-scale commercial producers. Much of the significant policy developments in the Fox era continued to support the facilitation of commercial farmers access to international and domestic markets. As we demonstrate, this policy direction was particularly advantageous to farmers in the Northwest.

The last period includes policy changes in response to social upheaval following the “tortilla crisis” in 2007 and more generally to perceived effects of NAFTA. The tortilla crisis refers to the significant increase in the price of tortillas that occurred in 2007, coincident with elevated grain and oil prices internationally. The period can also be interpreted as one of growing interdependence between U.S. and Mexican grain markets, urban maize consumers and the plight of rural, small-holder maize farmers. In terms of agriculture, maintaining high productivity in the northwest continued to be a policy priority focusing on large-scale production. In some states, efforts were made to support some small-holder farmer groups (Lerner & Appendini, 2011). Most recently (2011-present), a new program has been introduced by the Secretary of Agriculture in collaboration with the International Center for Maize and Wheat Research (CIMMYT). This program, MasAgro, aims to revitalize smallholder production nationally through targeted improved local maize varieties, and conservation and precision agriculture.

Spatial and organizational change

As noted in the introduction, the goal for this section is to identify dominant trends, spatial patterns, and associated organizational structures that characterize the regional evolution of Mexican maize production since 1980. The data we use is the Mexican annual agricultural survey (SIAP, n.d.).[9] The basic measures available for any crop include hectares planted, hectares harvested, volume of output, and the value of output (at the “farm gate”). From these we can derive measures for crop failure (area planted- area harvested), yield (output per unit planted), and price (value per unit output). The basic measures can be cross-classified by production method, time (year and season), and space. The spatial resolution includes national, state, rural districts, and municipalities. The national and state level data are available from 1980 to 2010 whereas rural districts are only available from 1999. The dominant large-scale evolution of spatial patterns relies on analysis of regions – groups of states. A map of the region boundaries and the location of major maize producing states is provided in Fig. 1.

[9] El Sistema de Información Agroalimentaria de Consulta: http://www.siap.gob.mx/index.php?option=com_content&view=article&id=286&Itemid=428.

Fig. 1. Regions and primary maize producing states. Note: States are in order of most to least output at the end of the period. End of period measure is as described in the note for Table 1. The states are: 1. Sinaloa, 2. Jalisco, 3. Mexico, 4. Chiapas, 5. Michoacán, 6. Guerrero, 7. Guanajuato, 8. Veracruz, 9. Puebla, 10. Chihuahua, 11. Oaxaca, 12. Hidalgo, 13. Tamaulipas.

There are several conceptual framing issues imbedded in the analysis. As noted in the policy review, there is a long history of two sectors co-existing in agriculture. The commercial sector is typically larger-scale and strives to use modern agribusiness practices; taking advantage of crop science (seed varieties, spacing, fertilizers), refined marketing (national scope, long-term contracts), and advanced logistics. The traditional sector is characterized by small-holder farmers (usually *ejidatarios*) growing “creole” maize varieties (local land races). For this sector, maize is typically more than an economic strategy. Maize production is embedded in cultural practices and social identity at the household and community levels. This dual-sector characterization is fundamental to understanding maize production but we only have a blunt proxy available as a measure: irrigated (commercial) and not irrigated (traditional). While there are certainly traditional farmers working in *ejidos* with irrigation, the policy history has tended to cement the link between commercial agriculture and access to irrigation. Since investment in irrigation favored specific regions, in particular the north, the culture of commercial farming and acceptance of modern agronomy follows a similar regional pattern.

The concept of maize is also fundamental. The vast majority of maize grown in Mexico is ‘white’ and is used to produce tortillas and other food products for direct human consumption. This is in contrast to industrial “yellow” corn production in the U.S.; primarily used as animal feed and to make industrial corn derivatives ranging from sweeteners to plastics. Again, the classifications in the data are imperfect and our analysis is based on the category *maiz grano* (maize grain). In the last five years of data, the category can be disaggregated into *amarillo* (yellow), *blanco* (white), *de color*, and *pozolero*. While yellow corn does seem to be increasing relative to white since 2005, the data for 2010 indicate that white is still dominant (national maize grain output is 91% white, 8.5% yellow, and 0.5% in the other two categories). This is important to establish in terms of national market dynamics within Mexico (whether commercial and traditional farmers compete head-to-head) and for gauging the risk posed by imports.

The last conceptual element has to do with seasonality. Maize is produced in two seasonal plantings. The *fall* crop is planted in November, harvested in May, and is typically under irrigation. The *spring* crop is planted in April, harvested in September, and is typically produced in rain-fed conditions. There are several interesting questions related to land area in maize. To assess land area (planted, harvested, or failed hectares) it is necessary to isolate the specific season. Aggregates over season will result in potentially double counting the same tracts of land and make interpretation difficult. Isolating seasons is also important because climate risks differ by season, and farmers in a particular region tend to plant predominantly in only one season.

National trends

National trends are summarized in Fig. 2 using four dimensions: area planted (upper left), crop failure area (upper right), output (lower left), and yield (lower right).

The total land area devoted to maize is clearly dominated by non-irrigated cropping. From about 1990 to 1994 the number of hectares under irrigated production almost doubled, then decreased to pre-1990 levels during the Zedillo administration. Since 2000 land devoted to irrigated production has steadily increased by roughly 49,000 ha per year while land in non-irrigated production has decreased by roughly 120,000 ha per year. While total land area in maize was equivalent in 1980 and 2010, the trends since 2000 suggest total area will continue to decrease below 1980 levels. It is possible, of course, that this trend could be reversed if there is a significant change in national policy. The new MasAgro program, for example, may be indicative of a change in national policy perspective.

There are two interesting trends in crop failure. First, almost all variation is from the non-irrigated sector. Second, the failure appears episodic with occasional spikes accenting a general background level of failure. That background level appears to be trending negative. As we discuss below, the 1983 failure spike, and several of

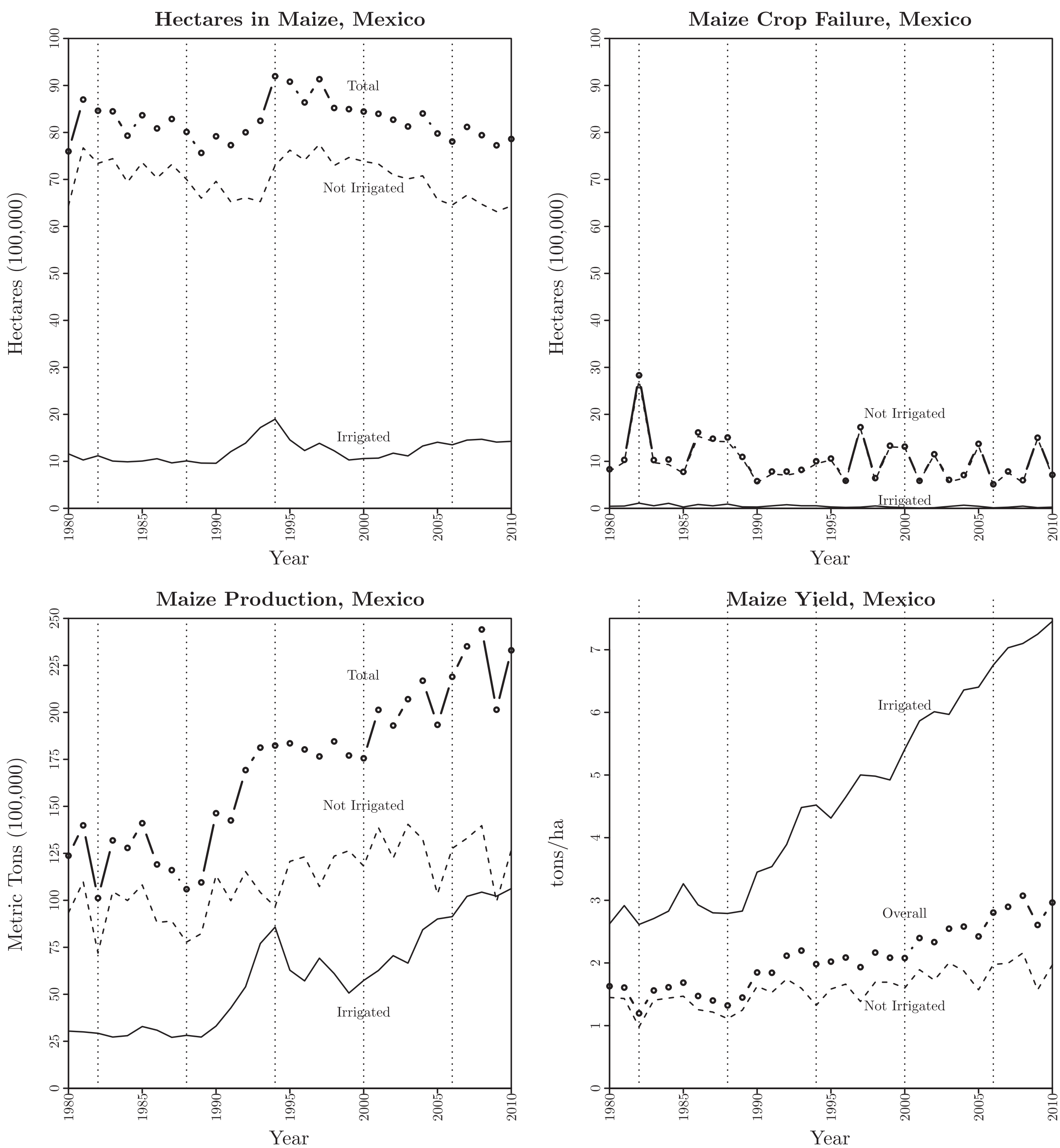

Fig. 2. National time series. Note: National time series for area planted (upper left), crop failure area (upper right), output (lower left), and yield (lower right).

the others visible in the national series are coincident with *El Nino* events or other weather-related extreme events (e.g. droughts, too much rain at the wrong stage of plant development, frost, etc.).

Maize production and yield exhibit much stronger trends than either of the area based time series. Total output climbs fairly steadily over the period observed. The 1989 to 1994 period of increasing irrigated hectares, shows up in these plots as the periods of largest output growth and largest gains in yield over the entire period. Unlike the area planted series, total output is trending positive since 1994. Some of that is due to compensating differences between the irrigated and non-irrigated sectors. As irrigated land was scaled back between 1994 and 1997, non-irrigated land increased slightly.

The other factor accounting for output growth is that the irrigated sector has experienced steadily increasing yields (about 5% per year) since 1989. The non-irrigated sector benefitted from increasing yields over the same period, but these are slight in comparison to the irrigated sector.[10] In summary, even though the irrigated sector constitutes a small share of the total land area planted in maize, because of the increasing yields it is contributing an increasing share of output every year. At the beginning of the period, only 25% of maize production used irrigation and by 2006–09 it had risen to approximately 45% of production. Also, because the irrigated sector is less susceptible to crop failure, its increasing share has had a stabilizing effect on total output.

Regional patterns

Since the major dynamic in the national series is the increasing role of irrigated production and the susceptibility of the non-irrigated sector to failure, it is important to establish how these trends are distributed spatially. An unequal spatial distribution would imply differential access to direct benefits, and exposure to risks, of the sector level trends.

Fig. 3 contains three panels showing, from top to bottom, the share of total output, the share of irrigated output and the share of non-irrigated output contributed by each region. These plots reinforce that the major dynamic over the 1980–2010 period is the shift toward output from irrigated production. As dictated by climate constraints, farmers in southern Mexico rely primarily on rain, farmers in northern Mexico use irrigation, and those in central Mexico use both production methods. The regional shares of non-irrigated production remained relatively constant until 2000, but since then the Centerwest and Southeast have increased output relative to the Center. In contrast to the relatively stable share of non-irrigated output, the Northwest and Centerwest have emerged as the dominant regions for irrigated maize. The Northwest region produced only 5% of irrigated output at the beginning of the period and grew to over 50% of output by the end of the period. The share of production in the Centerwest decreased slightly between 1980 and 2010, but this was during a period of rapidly increasing irrigated output at the national level. Since 2006, roughly 70% of irrigated maize is from the Northwest and Centerwest. Farmers in the Northeast and Center have slightly increased irrigated maize production since 1980, but the share of irrigated production from those regions has decreased.

The analysis of changing output shares captures the increasing “market share” of irrigated, Northwest producers, but fails to characterize how the changing allocation was achieved. For example, output gains could be realized from increasing the area planted, increasing yields, or both. Fig. 4 (Fall) and 5 (Spring) contains plots of the regional trajectories, by production method, through the coordinate space defined by area planted (*x*-axis) and output (*y*-axis). The plots include yield rays (dashed lines) defined by fixed ratios of output to area planted. Gray shading indicates the ellipsoid hull – a measure of the data range in 2-dimensions – associated with a policy period. Dark lines link the means centers of each ellipsoid hull, and symbols are used to mark locations of the mean centers.[11] The path defined by the dark lines and symbols provides a summary of regional trajectories over the last 31 years.

In the non-irrigated sector, the three dominant regions each followed different paths. Farmers in the Southeast region expanded maize output primarily by increasing area planted in maize during the spring with yields remaining fixed at about 1.4 tons/ha.[12] The largest increase in area planted occurred between the Salinas and Zedillo administrations coincident with the period of open market reforms. The most recent shift has been a decrease in land area while maintaining output with yields approaching 1.8 ton/ha. The much smaller fall planting season followed a similar pattern. In stark contrast to the Southeast, the farmers planting rain-fed maize in the Centerwest region have followed a steady path toward increasing yields. From the de la Madrid administration to the Fox administration, farmers have produced more output with less land, raising yields from 1.2 tons/ha to 2.3 tons/ha.[13] The pattern for the Center region is less dramatic but indicates area planted has been reduced, output has remained stable, and yields have increased from 1.6 to 2 tons/ha. Overall, the non-irrigated sector during the period of open market reforms has been characterized by strongly increasing yields in the Centerwest, moderately increasing yields in the Center, and proportionate increases in area planted and output in the Southeast resulting in constant yields. Increasing yields in the Southeast occurred primarily during the Calderón administration.

The irrigated sector includes a fall crop (northern) and spring crop (central and northern). While the Northeast region contributes to the fall crop, those contributions are marginal in comparison to the Northwest and average yields have ranged between 4 and 5 tons/ha. Farmers in the Northwest dominate the fall planting and have radically increased yields. On average, northwestern farmers increased area planted during each administration since Madrid. During the same period, output grew at an even faster rate with yields increasing from an average of 2.8 tons/ha during the Salinas administration to an average of 9.8 tons/ha since 2006.

The irrigated spring crop in the north has exhibited less of a trend. The spring planting in the Northwest has intermittently (1986, 1992–1994, 1997) expanded to twice the usual area planted, but since 2000 has averaged only 30,000 ha compared to over 400,000 ha planted

[10] Case study data has demonstrated that farmers tend to reserve irrigated land for hybrid maize varieties, largely to ensure that they get a return on their investment (Eakin, 2006); the connection between use of modern varieties and irrigation has also been found using large survey sample data (Arslan & Taylor, 2009).

[11] x_t = area planted in maize and y_t = metric tons of maize harvested. For a given policy period, $t = 1982, \ldots, 1988$, the ellipsoid hull is the ellipse that exactly contains the points for that period. The mean center is defined as the weighted means of x_t and y_t with weights of 0.5 on starting and ending years (e.g. 1982, 1988) and weights of 1 for the interior points (e.g. 1983, …, 1987). For the first policy period, the early de la Madrid period is combined with Portillo to create a policy period from 1980 to 1985, and the latter part of de la Madrid period is combined with Salinas to create a period starting in 1986 and ending in 1994. Those adjustments are consistent with changes in policy direction. All other periods are the presidential *sexenios*.

[12] This expansion is consistent with Klepeis and Vance (2003) research that documents an acceleration in deforestation throughout this region during the same period.

[13] The analysis we present here for the Centerwest is consistent with recent research using remote sensing of land use/land cover change that shows a large reduction of agricultural lands within a region of Michoacán and Guanajuato between 1986 and 1996, and continuing reductions thereafter Mendoza, Granados, Geneletti, Pérez-Salicrup, and Salinas (2011).

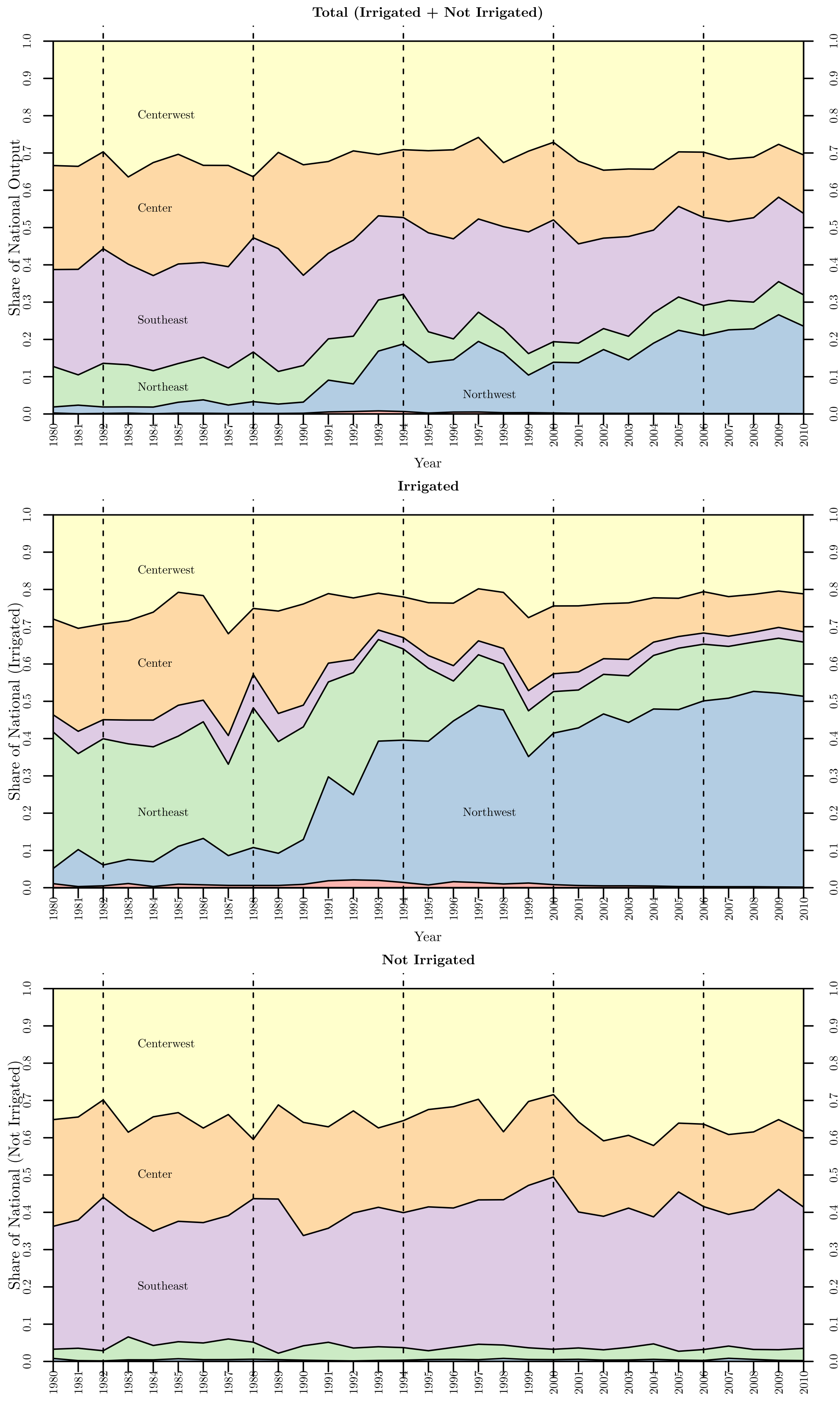

Fig. 3. Regional share of national output, 1980–2010. Note: Regional shares over time are depicted for total output (top), irrigated output (middle), and non-irrigated output (bottom).

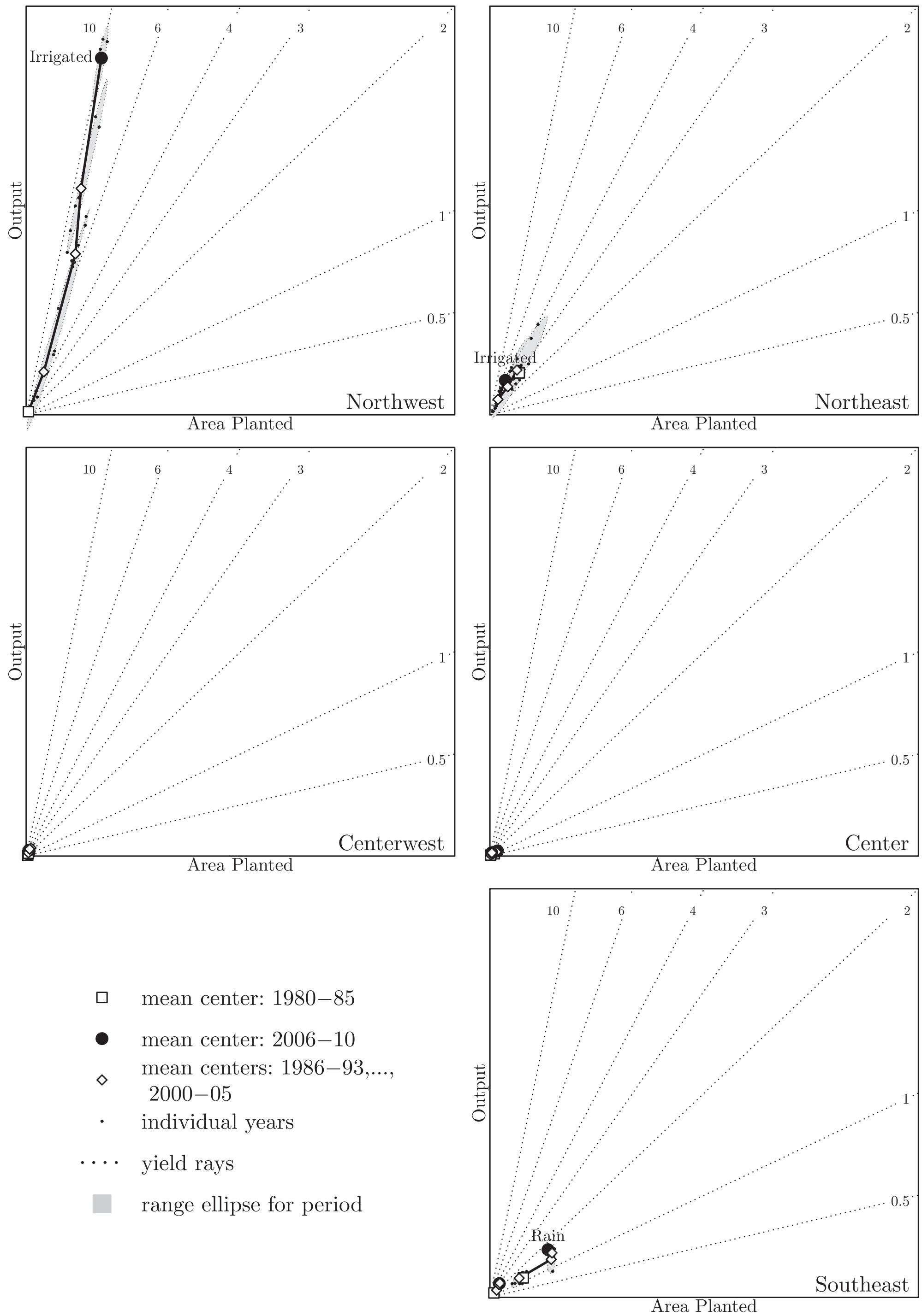

Fig. 4. Fall: Output and area planted regional trajectories, 1980–2010. Note: Plotting fall output (*y*-axis) against area planted (*x*-axis) over time for each of the five regions. The plots include yield rays (dashed lines) defined by fixed ratios of output to area planted. Gray shading indicates the ellipsoid hull a measure of the data range in 2-dimensions associated with a policy period. Dark lines link the means centers of each ellipsoid hull, and symbols are used to mark locations of the mean centers. The path defined by the dark lines and symbols provides a summary of regional trajectories over the last 31 years.

during the fall. Similar to the fall planting season, yields have increased to 8 tons/ha. Farmers in the Northeast have maintained a relatively stable area planted of 120,000 to 150,000 ha, but they also doubled their planting area from 1992 to 1994. Yields in the Northeast have always lagged behind the Northwest and by the end of the period were averaging 7 tons/ha.

The irrigated spring crop in the Centerwest has steadily increasing yields with almost no change in area planted. But the average yields during the last three years, 6.4 tons/ha, are far lower than what farmers have achieved in the north. Maize farmers in the Center have remained relatively stable with only slight decreases in area planted and slight increases in yields (from 3 to 4.5 tons/ha) for the spring irrigated crop.

The major theme at the regional level is that while the commercial sector exhibits more dynamism as a whole, the sector performs differently in each region. The Northwest is clearly the most dynamic and its performance is dominating the irrigated sectors in

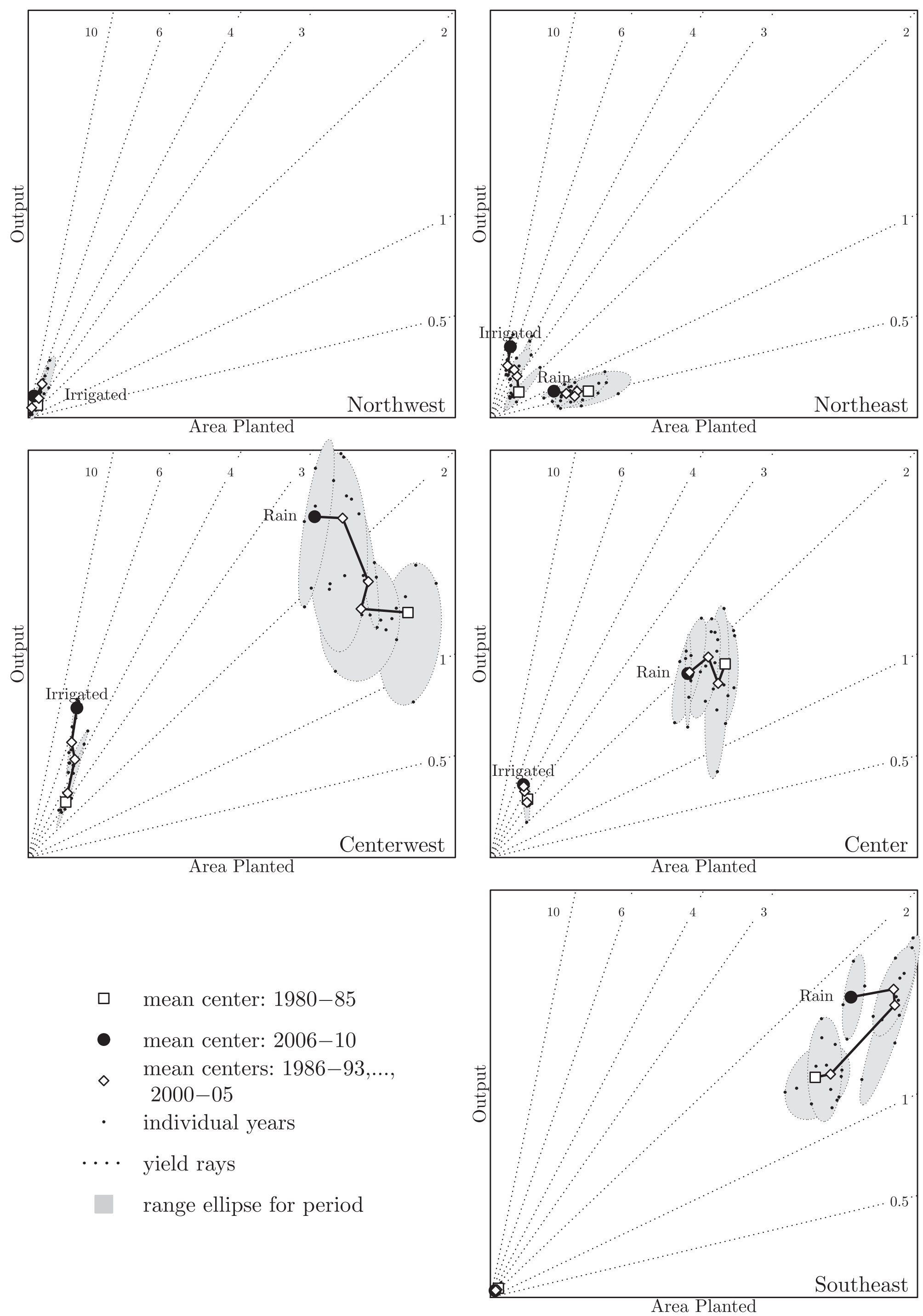

Fig. 5. Spring: Output and area planted regional trajectories, 1980–2010. Note: Same plotting approach as Fig. 4 but now focus is on the spring maize crop.

the Northeast and Centerwest. These differences are particularly stark in terms of yield. To put this in context, over the last ten years the commercial sector in the Northwest has had yields at or above the yields of U.S. corn growers.[14] The non-irrigated sector has more variation in output because of its exposure to climate-induced crop failure. Still, by examining the means for each presidential term, there are strong regional patterns. While the Centerwest lagged behind the north in irrigated yields, it has the highest yields and the largest gains in yields for the non-irrigated sector. The only large increase in non-irrigated area planted was in the Southeast, but between the Fox and Calderón administrations the area devoted to non-irrigated maize production was decreased.

Changes in state level production

The region level analysis captures the dominant spatial and organizational shifts underway in Mexico. But variation in production

[14] The three year average yield for the period 2007–09 for U.S. corn growers is 9. 4 tons/ha.

strategies among states indicates that dominant patterns of production prior to 1980 are shifting within regions. The broad changes in state output over the study period are captured in Fig. 6. While the massive growth in output in Sinaloa dwarfs all other state level changes, three different states in the Centerwest (Jalisco, Michoacán, and Guanajuato), Guerrero (Southeast) and Chihuahua (Northeast) also had large increases in output. But the states of Mexico and Chiapas, historically among the top three producers, either declined or stagnated.

A more detailed assessment is possible with the aid of Table 1. Sinaloa dominates the Northwest region and so the description given in the previous section is reflected again in the state level statistics. It is unique in terms of focusing on fall production with almost complete reliance on irrigation, and it has the highest yields.

The three growth centers in the Centerwest are similar to each other in that they focus on the spring crop and increased output through higher yields (the area planted actually decreases); but Jalisco's production is almost entirely rain-fed whereas Michoacán and Guanajuato have shifted toward more reliance on irrigation. Guanajuato is one of two states with irrigated yields approaching those in Sinaloa. Jalisco is particularly notable because farmers in the state are adopting commercial production strategies without irrigation.

In the Northeast, spring production has almost been eliminated in Tamaulipas, and while the fall crop is still second to Sinaloa for the season, the yields are lagging well behind. More striking is that Chihuahua has emerged as an important center of irrigated spring production with yields only slightly lower than Sinaloa's fall crop. Other researchers have noted that the new production center in Chihuahua is also significant because they are focusing on yellow maize (feed corn). This makes sense given its proximity to the major centers for cattle and pork production. One other important aspect in Chihuahua is that the annual variation in production is much higher than in Sinaloa. This is probably because drought conditions are more likely to impact Chihuahua, restrict irrigation, and that would almost certainly cause widespread crop failure.

The states in the Center region are characterized primarily by stagnancy and decline. The decreased output from the state of

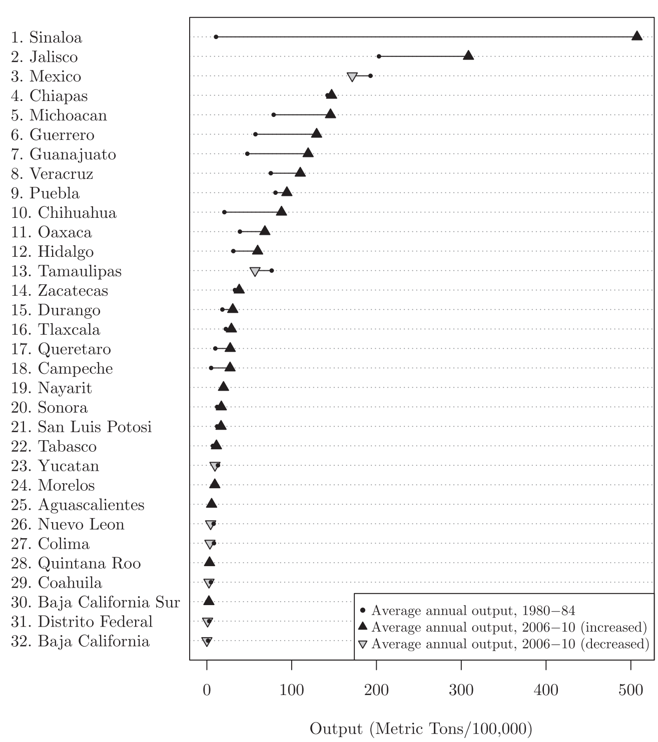

Fig. 6. State maize production, 1980–84 to 2005–09.

Mexico, due to land being removed from production, has just barely been offset by increases in Hidalgo. While yields have doubled for the irrigated crop in Hidalgo, the yields in Puebla and Mexico have stagnated.

The major maize producing states in the Southeast region are also following different paths. Chiapas, Oaxaca, and Guerrero are similar in that production increases were driven by increasing the area planted rather than yield-driven increases found in the North and Centerwest. Veracruz is distinct in the Southeast in having relatively balanced growth distributed over the fall and spring seasons, having production gains that are primarily due to increasing rain-fed yields, and having low annual variation in output as measured by the coefficient of median dispersion.

The heterogeneity among states within a region means that some of the regional patterns need to be interpreted cautiously. At the regional level it appeared that the Center was holding stable and recording small gains in yields. In fact, the historical production center in Mexico state is declining and the regional pattern is due to other states having compensating production increases. In the Northeast, the state pattern reveals a major relocation of production within the region from Tamaulipas to Chihuahua.

Rural districts: spatial patterns of crop failure

The national trends together with the regional and state patterns characterize the traditional sector as not only stagnant (in terms of yields) but also exposed to much higher incidence of crop failure. The only real exception to this pattern is the commercialized rain-fed sector in Jalisco. Most of the uncertainty in national maize output is from large inter-annual variations in crop failure. In this section we examine fine spatial resolution variation in crop loss.

The data provides a direct measure of crop loss; *hectares planted* minus *hectares harvested*. Unfortunately the direct measure is not particularly useful for comparative analysis. We do not have a good measure of total arable land in each district so we cannot express loss as a relative measure. Also, we are ultimately interested in lost output and that amount will differ depending on the yield in the specific district and sector. Our solution is to define *estimated output lost to crop failure*.

The annual agricultural survey provides for each rural district i (=1,…, 195), growing method j (=1 "irrigated",=2 "not irrigated"), season k (=1"Fall-Winter",=2 "Spring–Summer"), and year t (=1999…2010):

S_{ijkt} = hectares sown in maiz,
f_{ijkt} = hectares sown that failed prior to harvest ($f_{ijkt} \leq s_{ijkt}$), and
y_{ijkt} = output harvested in metric tons.

Yield is calculated as y_{ijkt}/s_{ijkt}; output (metric tons) per hectare planted. An alternative approach is to define yield as output per hectare *harvested*: $y_{ijkt}/s_{ijkt}-f_{ijkt}$. Assuming that the lost hectares would have produced at the same yield as those that were harvested, define estimated output lost to crop failure as:

$$\widehat{y}^{\text{failed}}_{ijkt} = f_{ijkt}\cdot\frac{y_{ijkt}}{s_{ijkt}-f_{ijkt}} = y_{ijkt}\cdot\frac{1}{\frac{s_{ijkt}}{f_{ijkt}}-1}.$$

The spatial distribution of $\widehat{y}^{\text{failed}}_{ijkt}$ for the years 2002, 2008, and 2009 are displayed in Figs. 7–9. Notice that the cut points, associated with grayscale colors, correspond to increasingly large ranges reflecting the skewed distribution of the lost output.

Recall from Fig. 2, that crop failure measured as hectares lost appeared to only impact the rain-fed sector. While estimated

Table 1
State production characteristics.

	State	Rank	Output		Area planted				Yield			
									Irrigated		Rainfed	
			$\bar{y}_{t_1} - \bar{y}_{t_0}$	MD (Δy)	$\bar{s}_{t_1} - \bar{s}_{t_0}$	p_{t0}	p_{t1}	MD (Δs)	t_0	t_1	t_0	t_1
Fall	Sinaloa	1	47,140	0.02	4596	0.85	0.99	0.05	2.6	10.1	1.3	1.1
	Jalisco	14	46	0.22	−8	0.59	0.68	0.19	2.8	4.3	0.9	2.3
	Mexico	24	4	0.09	1	0.74	1.00	0.07	2.6	2.7	2.1	
	Chiapas	4	1099	0.21	754	0.11	0.08	0.09	3.2	3.6	1.2	1.3
	Michoacán	13	56	0.11	6	1.00	0.97	0.14	2.5	3.2	1.3	2.7
	Guerrero	7	637	0.15	149	0.76	0.94	0.28	2.6	3.5	1.3	2.8
	Guanajuato	16	80	0.02	9	0.98	1.00	0.06	3.5	7.4	0.1	
	Veracruz	3	1987	0.07	323	0.02	0.01	0.06	2.5	5.1	1.2	2.0
	Puebla	9	375	0.23	178	0.07	0.19	0.11	2.9	3.3	1.2	1.4
	Chihuahua	27	0	0.00	0		0.00	0.00				0.4
	Oaxaca	6	895	0.25	369	0.28	0.34	0.27	1.6	2.3	1.3	1.7
	Hidalgo	10	373	0.23	115	0.03	0.15	0.10	3.2	4.9	1.0	1.5
	Tamaulipas	2	−820	0.08	−1059	0.88	0.94	0.09	2.9	4.7	0.8	1.6
Spring	Sinaloa	13	2509	0.12	−405	0.18	0.37	0.29	1.7	8.5	0.3	0.9
	Jalisco	1	10,510	0.10	−2511	0.06	0.06	0.19	2.8	7.0	2.3	5.0
	Mexico	2	−2156	0.15	−1518	0.17	0.18	0.17	3.3	3.9	2.6	2.8
	Chiapas	4	−615	0.08	−103	0.01	0.00	0.03	2.9	3.0	2.2	2.2
	Michoacán	3	6650	0.30	−272	0.14	0.20	0.19	2.8	5.6	1.4	2.5
	Guerrero	5	6579	0.12	300	0.02	0.02	0.08	2.2	3.8	1.3	2.6
	Guanajuato	6	7089	0.19	−476	0.13	0.28	0.23	4.1	7.8	0.6	1.2
	Veracruz	9	1485	0.02	−304	0.02	0.01	0.03	2.7	4.1	1.3	1.8
	Puebla	7	968	0.07	−285	0.07	0.08	0.06	3.0	4.3	1.2	1.4
	Chiuahua	8	6737	0.34	−720	0.10	0.36	0.20	2.2	8.9	0.5	1.0
	Oaxaca	10	2050	0.09	1266	0.05	0.03	0.17	2.0	2.4	0.8	1.0
	Hidalgo	11	2489	0.28	−114	0.24	0.23	0.20	3.2	6.7	0.6	1.1
	Tamaulipas	22	−1144	0.07	−1047	0.43	0.12	0.04	1.7	2.4	0.7	1.1

Note: States are in order of most to least output at the end of the period. The "Rank" refers to end of period output relative to all 32 states in fall (top panel) or spring (bottom panel). Output (y) is measured in 100s of metric tons and area planted (s) in 100s of hectares. The beginning and ending period measures are five year averages (e.g. $\bar{y}_{t_0} = (\sum_{i=1980}^{1984} y_i)/5$ and $\bar{y}_{t_1} = (\sum_{i=2006}^{2010} y_i)/5$). Relative dispersion of the annual changes in output (Δy) and area planted (Δs) is measured using the coefficient of median dispersion (MD). p_{t0} and p_{t1} are the proportion of land irrigated. Grey shading indicates absolute decreases in output or area planted over the period.

output lost is similarly pervasive in the rain-fed sector, there are years like 2008 when relatively small losses in area translated to large output losses in the irrigated sector. The largest maize crop losses were in four of Sinaloa's rural districts; failed hectares included 11,281 (Culican), 6034 (Los Mochus), 2318 (Guasave), and 794 (Guamuchil). The total lost output for the four DDRs was roughly 207,000 metric tons, or a 1/5 of the total lost maize output in 2008. The crop losses in this region were most likely related to Hurricane Norbert. It reached mainland Mexico in early October, the center of the storm passed near the border of Sinaloa and Sonora, and it caused major flooding throughout Sinaloa (Luis, 2009). In February 2011, another major crop failure resulted from a weather anomaly. An arctic air mass pushed south and frost killed a large portion of the Sinaloa fall crop. Of the 800,728 ha planted, more than half of that (413,105) was destroyed by the frost (Eakin, Bausch, & Sweeney, in press; SIAP, n.d.).

The spring, rain-fed crop exhibits the most spatially extensive and unstable patterns of crop loss. Using Fig. 2 as a guide to national outcomes, 2002 and 2009 represent failure events, in terms of hectares lost, that are similar in severity to other events since 1980. The year 2008 reflects the general background failure rates in the rain-fed sector. The spatial extent of failure is not surprising since it reflects the ubiquitous practice of planting maize in climates that will support it without irrigation. This means that the crops are vulnerable to any climate anomolies. The instability, or unique footprint, associated with the two severe failure events most likely reflects the specific climate impact that caused the failure. The 2009 crop failures are related to the worst drought in 70 years to hit central Mexico (Juarez & Ford, 2009; Patricia, 2009).[15] The 2002 losses resulted from several different events. Hurricane Isidore is responsible for losses in the Yucatan and particularly Campeche, while Guerrero, Oaxaca, and Chiapas were hit by higher than average late season rains.

Discussion

While policies have generally drifted toward less government intervention in maize production, the dual-sectors continue to coexist. The major change is that the commercial sectors have now fully embraced maize and there are now distinct regional production regimes that were not present 30 years ago. The commercial sector has continued a rapid pace of modernization and has established a vibrant new production center in the Northwest primarily driven by a small number of rural districts in Sinaloa. The Sinaloa farmers have been entrepreneurial in quickly adopting the most modern production methods, but also politically astute as they have been the primary beneficiaries of government programs targeting commercial producers (Eakin et al., in press). The two other major commercial maize centers, Centerwest and Northeast, have had much smaller gains in yields.[16] This reflects differences in production strategies and environmental constraints, but may also reflect spatial bounds on the political economy of commercial maize production. For example, Eakin et al. (in press) found that Sinaloa was a specific target of public investment in the 1990s, something that perhaps was not reflected in Tamaulipas. In the Northwest, the modernization has resulted in yields that have been

[15] A map of the relative drought severity is at: http://www1.ncdc.noaa.gov/pub/data/cmb/hazards/2009/08/mexicodrought-200907.gif.

[16] There is also an important commercial sector in La Frailesca, Chiapas that is below the scale of analysis in this paper but has been the focus of extensive study as reported in Keleman, Hellin, and Bellon (2009), Hellin, Keleman, and Bellon (2010), and Bellon and Hellin (2011).

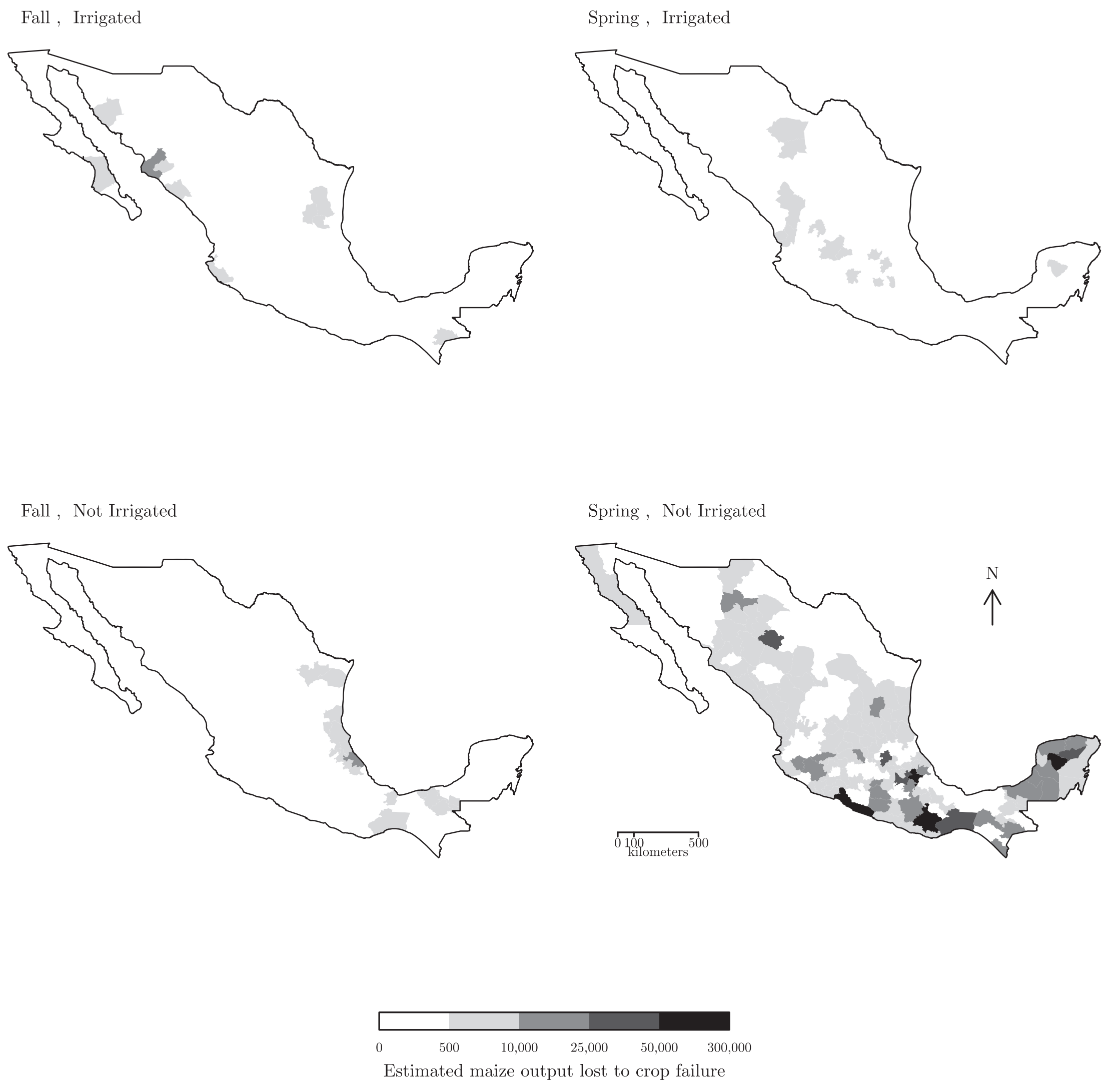

Fig. 7. Estimated crop loss, 2002.

comparable to U.S. corn farmers since 2000. The combined output of the Northwest and Northeast amounts to approximately 35% of national output. While the transformation of the commercial sector is impressive it is likely that technology-driven gains are approaching upper limits for the Sinaloa farmers which may also be binding for US farmers (Cassman, 1999).

The temptation is to view the traditional and commercial sectors as direct competitors. While there are certainly some areas where traditional, rain-fed production is retreating, the broad trend from 1980 to 2009 is that rain-fed production has remained stable in the Center region and has *increased* in the Southeast region. In both regions, this was accomplished through increases in yields, and since the Fox administration the area planted has been decreasing. This suggests that perhaps less efficient farmers have been abandoning maize, while the remaining farmers have been striving to increase yields (see for example, results of Bellon and Hellin (2011)). From the state level results it is apparent that decreased output in one state has generally been offset by other states in the same region. Certainly, from 1980 to present the demand for white maize has grown, and with the policy of national self-sufficiency, decreased output in one area has to be more than compensated for by increases in other areas. Even with overall increased efficiency at the level of the whole maize production system, there is a massive gulf in productivity between the commercial sector and the traditional sector *and* between the North and South. The highest yields in the fully commercialized rain-fed sector during the last five years was 4.7 tons/ha in Jalisco, lower than the yields in Jalisco's, Michoacán's, or Guanajuato's irrigated sectors around 1980, and substantially lower than the yields of 9.8 tons/ha in Sinaloa. This makes it even more intriguing that the rain-fed sector has persisted. It seems to imply that the commercial and traditional sectors are to some degree occupying different markets while producing the same crop. This is borne out in related work, such as that of Barkin (2002) and Keleman and Hellin (2009). In the latter case, the authors found that smallholder farmers are finding opportunities in specialty maize markets. Previous research by de Janvry, Sadoulet, and De Anda (1995) predicted exactly this outcome based on *ejido* surveys that found small-holder farmers were relatively disconnected and

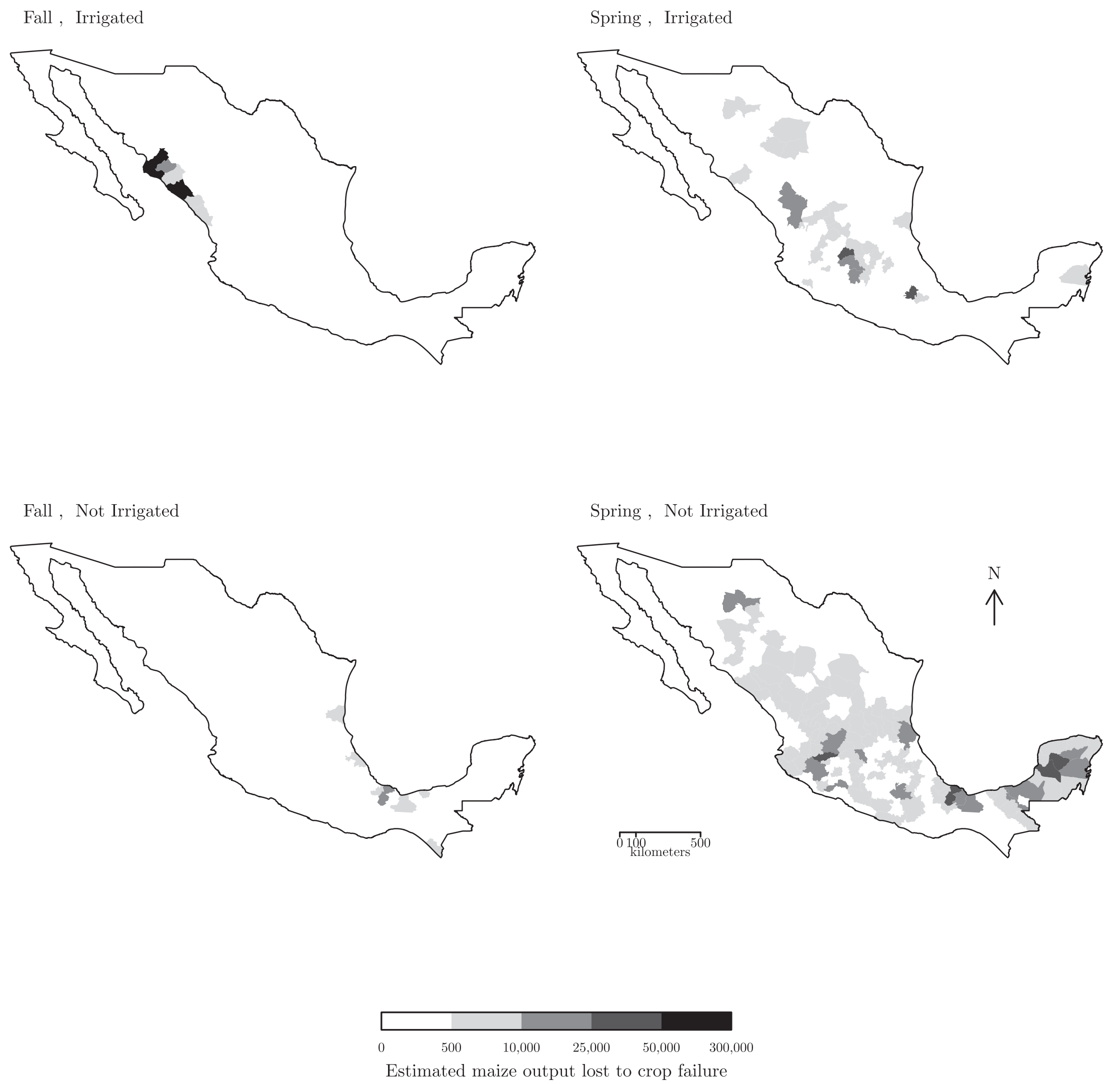

Fig. 8. Estimated crop loss, 2008.

insulated from maize prices because they were producing for household consumption rather than market sales.

What has been the role of the various policy changes and free trade agreements in relation to the spatial and organizational changes in maize production? Overall, the combined effect suggests that modernization strategies have been successful. But that assessment has to consider near term direct and indirect policy impacts, and the lasting effects of historic policies. Certainly the groundwork for the current commercial maize sector is due to irrigation infrastructure investments that date to the 1960s and continued into the 1980s. Over that period, the emphasis in those sectors had been wheat, fresh fruits and vegetables for export, and to a lesser degree sorghum (for animal feed). Those long term investments cultivated a commercial agriculture sector but the market and government incentives up through the 1980s did not favor commercial maize production.

The large-scale domestic and international policy changes during the Salinas to Fox administrations likely had strong indirect effects on commercial maize production. Maize and beans were the last crops to loose price supports and that only happened in 2008. As profit margins shrank for other grains due to international competition,[17] the switch to maize farming may have been the best financial option with the best long-term prospects (DeWalt, Rees, and Murphy, 1994; Fritscher-Mundt, 1999; Garcia-Salazar & Williams, 2004; de Janvry, Gordillo, & Sadoulet, 1997). The timing of the rapid production increase in Sinaloa is consistent with this hypothesis (Eakin et al., in press). The rapid transformation from 1989 to 1994 is coincident with the devolution of ASERCA and subsequent market reforms and commercial assistance have served to reinforce steady growth in the commercial sector. A frequently stated concern about NAFTA, especially in the early 1990s, was that market integration would depress incentives for production in Mexico, leading to increased dependence on imports (Baffes, 1998;

[17] Wilder and Whiteford (2006) discuss the impacts of NAFTA on rice and wheat farming, and the agreement of the free trade agreement with Chile on grape and raison production. For rice, "…when faced by highly subsidized rice production in the United States, more than 30,000 rice producers in Mexico had to abandon rice cultivation and almost half of the rice processing mills closed." (350).

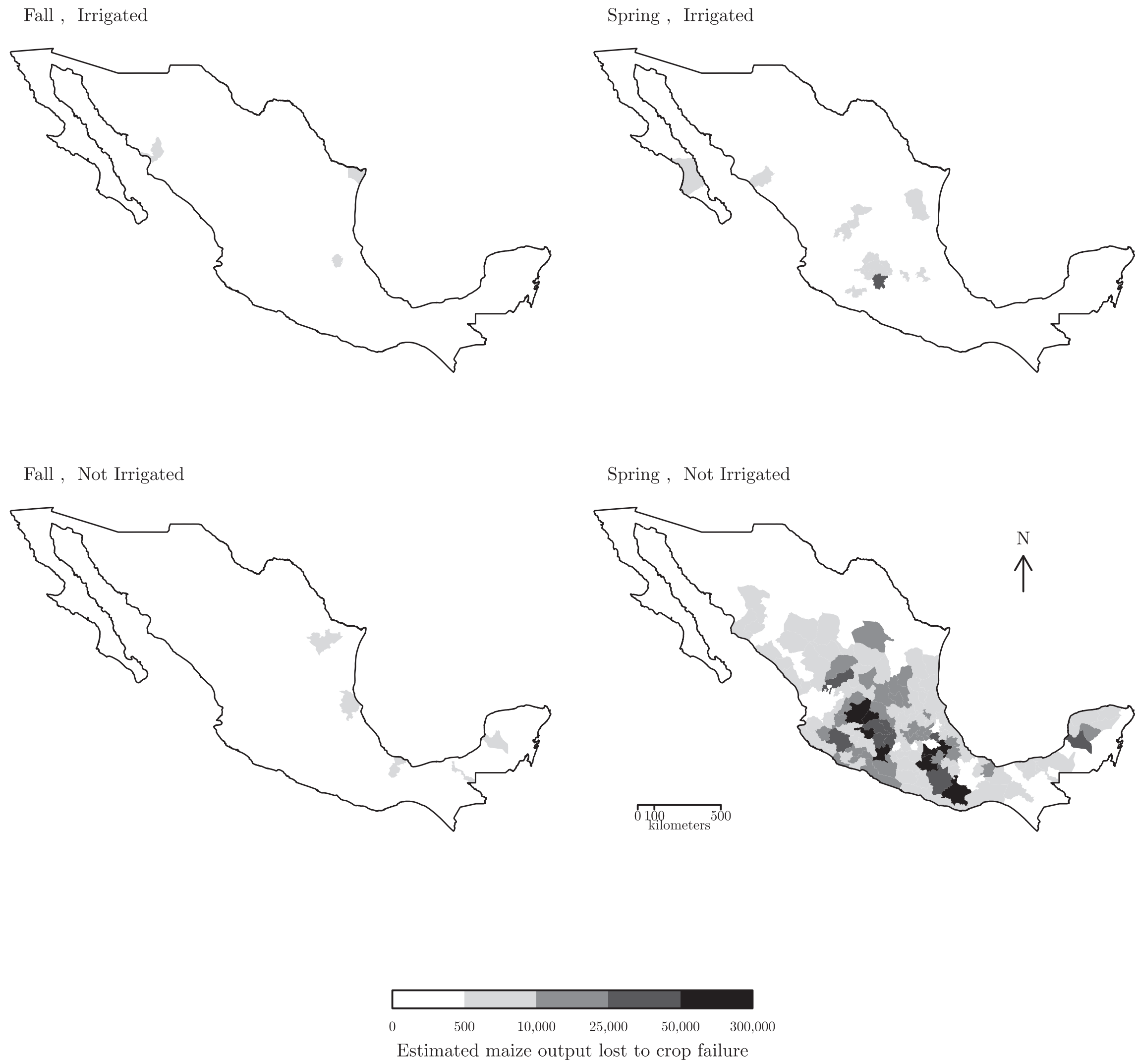

Fig. 9. Estimated crop loss, 2009.

Rello & Pérez, 2010), and indeed maize imports from the U.S. have increased substantially as a result of the trade agreement. But as noted already, the U.S. produced yellow corn supplies an entirely different market segment (animal feed, refined corn products) than Mexican grown white corn. The U.S. does produce white corn and exports about half of that production to Mexico, but those exports are equivalent to only 1% of Mexican white maize production. Exports of white corn to Mexico had been nominally subject to quotas, but since those were rarely enforced (Fritscher-Mundt, 1999; Garcia-Salazar & Williams, 2004; Nadal, 1999), it is an open question whether U.S. farmers will seek to supply more of this market segment in the future.

The policies with respect to the rain-fed sector, and particularly small-holder and *ejido* farmers, have changed drastically over the study period. The market liberalizing reforms removed incentives for small-holders to grow maize while providing payments (PROCAMPO) to support the displacement from that component of their livelihood. At the same time a constitutional reform gave *ejido* farmers titles to their land, which was thought would encourage them to sell or rent their land to more efficient producers. The initial expectation among some analysts and policy-makers was that this would lead to widespread abandonment of small-scale commercial maize farming (de Janvry, Chiriboga, et al., 1995; Rello & Pérez, 2010). As noted already, the sector appears to be persisting. This may be because the mix of policy reforms never fully abandoned the sector, but rather re-focused investment on social services for rural areas that were considered less competitive in national maize markets (Bartra, 1996; Eakin, 2006). An alternative explanation is that the sector persists because it is so deeply embedded in rural culture and livelihoods (for household consumption) and that there were insufficient “pull” factors in urban areas to stimulate full abandonment.

Even though the small-holder sector appears to be persisting in growing maize, it does not imply that policy shifts have had no impact on rural livelihoods. While small-holder farmers have been criticized for their inefficiency, the ability to both eat and sell maize was integral to their livelihood strategy. The shift in policy toward the commercial sector, and the decreased options to market crops for small-holder farmers, means that rural households have had to adjust their livelihood strategies to compensate. In many cases, this will have resulted in real losses for rural households.

The other central question we proposed at the outset was whether environmental risks have changed given the new patterns of production. The major effect in terms of climate risk is that the new patterns represent a trade-off. Irrigation and associated production technologies shield the crop from short-term droughts but not necessarily other hazards. Since the commercial production has focused on only a few regions, the impact could be catastrophic from a relatively small but targeted extreme event. Examples of this include Hurricane Norbert in 2008 and frost damage in February 2011. The rain-fed sector has broader exposure because production is spatially extensive. Droughts, hurricanes, and other environmental hazards can disrupt production and even result in 100% failure in some areas. But since the production is more extensive, it is also more robust. It is difficult to imagine a combination of climate events that could completely wipe out a single spring season of rain-fed maize production. The overall result of the shift toward a greater share of irrigated production in national output is that average inter-annual variation has decreased, but there is higher risk of large-scale losses that could result from a single storm.

In addition to the extreme event hazards, there are also longer-term environmental risks related to the new geography and organization of maize production.[18] Under some scenarios of climate change, the area considered most suitable for rainfed maize production is expected to decline, although the severity of impact is expected to vary by region (Monterroso Rivas, Conde Álvarez, Rosales Dorantes, Gómez Díaz, & Gay García, 2011). Under several scenarios, drying trends and increased drought risk are expected in much of the arid north and central *altiplano* where both irrigated and rainfed maize are grown (Boyd and Ibarrarán, 2009; Joint Global Change Research Institute, 2009). Climate change thus introduces uncertainty into the future of both modes of maize production. In addition to pure climate impacts, there are other issues related to seed diversity and the long run sustainability of all aspects of production. "Creole" varieties are lower yielding than the latest commercial seed varieties, but the mono-cultures characteristic of higher yielding commercial production also come with risks. The yield "miracle" in Sinaloa has also required intensive fertilization, pesticide use, and water use. The environmental implications of this change have yet to be documented, but some stakeholders in the state are beginning to raise concerns over pesticide resistance, water quality, and excessive input use (Eakin et al., in press).[19] It is not yet known whether climate changes that entail an increase in drought frequency would threaten surface water capacity and thus the viability of irrigated maize in the future (Eakin et al., in press). As such, although the government of the state of Sinaloa considers its high-yielding maize sector a model for the nation (Eakin et al., in press), there are many aspects of production that would be difficult to implement elsewhere in Mexico.

A last consideration is the sustainability of the current political economy that is intimately tied to the changes in maize production. It is interesting to consider that the path Mexico has been following started because the large government programs supporting the rural sector became fiscally unsustainable after Mexico defaulted. In many ways, the most recent policy path has continued to be "dual-track". The government continues to support small-holder farmers through PROCAMPO payments and the commercial sector has emerged as a more politically powerful and expensive component of government support than prior to market liberalizing reforms. There are many positive aspects related to the reforms – Mexico is self-sufficient in white maize production, maize producers are more efficient and trending toward even more efficiency – but it is not clear that the political trajectory supporting the current production system is sustainable.

[18] An alternative approach to what we present here would be to reduce all threats to the sector into a single vulnerability index, for example (Antwi-Agyei, Fraser, Dougill, Stringer, & Simelton, 2012). But the complex political, sectoral, and environmental context in Mexico is not suited to such an analysis.

[19] Díaz-Caravantes and Sánchez-Flores (2011) provides an insightful analysis of how droughts and politics of water transfers may interact to alter land uses in the north of Mexico.

Acknowledgments

This work was supported by the National Science Foundation, Grant no. BCS-0826871. The paper benefitted from the insightful comments provided by anonymous reviewers. We also thank Kirsten Appendini, Hugo Perales, and Amy Lerner for comments on early versions of the manuscript.

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