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Farm Households in Egypt

A typology for assessing vulnerability to climate change

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ABSTRACT

Using governorate-level national data and household survey data, we build a typology of farm households in Egypt that allows us to describe how different farm households behave in response to policy and environmental changes affecting their resources, welfare, and opportunities in output and input markets. One of the major contributions of this study is the building of a unique dataset that combines various data sources at different levels of aggregation, providing the information needed to model the farm typology. We used this dataset as the input of a multi-step procedure that includes the use of principal components and cluster analyses to identify 14 household types.

To illustrate possible uses of the typology, we look at the vulnerability of the different types of households to projected changes in temperature, water availability, and water demand from crops due to climate change, and discuss which farmers, production systems, and regions will be most affected by climate shocks. We assumed that increased temperatures by 2050 would result in increased water demand and reduced yields for most crops due to heat stress and harsher growing conditions. We define three climate change scenarios that differ in the expected water flows of the Nile into the Aswan High Dam.

Results of simulations using a household model suggest that Egypt is likely to experience a significant reduction in output, agricultural labor demand, and cultivated area because of climate change, although the severity of this outcome will depend on the magnitude of changes in the Nile's flow. Most affected by these changes will be small and average households producing field crops. Our results suggest that to mitigate the risks and possible future impacts of climate change, the country will need to:

- Move away from policies supporting production of cereals and water-inefficient crops towards diversification of production into water-efficient high-value crops;
- Facilitate the access of skilled resource-poor producers to capital and markets; and
- Create opportunities for off-farm employment and income for smallholders that are using resources inefficiently and who have limited possibilities to change to more efficient farming systems.

1. INTRODUCTION

To achieve and sustain food security and reduce rural poverty globally, sustainable agricultural production and food systems must be adopted worldwide. Egypt is no exception. While the opportunities and challenges facing the agricultural sector in Egypt are well known, the related policy advice to address the issues is often overly general and not necessarily targeted at specific regional and farm characteristics. Such general policy advice includes increasing water use efficiency and preserving soil quality, particularly given Egypt’s heavy dependence on irrigated agriculture and external water resources and in the face of a changing climate; improving input and output marketing; and linking farmers to knowledge and improved agricultural technologies.

However, there are many different types of agricultural producers and farm households in Egypt, and their specific needs and constraints are likely to differ significantly depending on key characteristics, including farm size; dependence on agricultural income; types of production systems and specialization; and location, particularly, Lower versus Upper Egypt; among many others. To address this diversity and to be better able to provide more targeted solutions, we use governorate-level and household survey data to build a typology of farm households in Egypt. This household typology approach allows us to describe how different farm households are likely to behave in response to policy and environmental changes affecting their resources, welfare, and opportunities in output and input markets.

Unlike household typologies that look only into farm features and production, we take a broader approach looking at household characteristics. In doing so, we follow Briggeman et al. (2007) who argue that decisions with respect to resource allocation occur at the household level rather than at the farm level. This is clearly the case in Egypt where a large proportion of farmers receive substantial income from non-farm sources and where a strong link exists between rural households and labor markets (Enbaby et al. 2016; Nin Pratt et al. 2018). Under this situation, shocks to off-farm income, employment, and wealth could have broader financial impacts for households than would be caused by shocks to agricultural income. Such off-farm shocks can also affect the allocation of household resources to agricultural production. Moreover, unlike unidimensional typologies like those grouping farm households based on landholding size, the multidimensional typology proposed here captures heterogeneity of farm households in terms of sources of income, wealth, and resource availability and is better suited to understanding both the intended and unintended economic and political consequences of farm policy (Briggeman et al. 2007). To illustrate possible uses of the typology in farm or sector-wide models, we look at the vulnerability of different types of Egyptian farming households to projected changes in temperature, water availability, and water needs from crops due to climate change. Using these results, we then discuss which farmers, production systems, and regions will be most affected by climate shocks and which policies could more effectively mitigate the negative impacts of climate change.

The paper is organized as follows. The next section gives a short background on Egypt’s agriculture and policy issues in the sector. Section 3 discusses data sources and data limitations. Section 4 presents the methodology used to develop the farm typology, while section 5 presents the household types and their main features. Section 6 presents the methodology and assumptions used in the simulation of the climate change scenario, looking at the vulnerability of different household types to climate shocks. Results and discussion of the impact of different climate change scenarios are discussed in section 7. Section 8 concludes.

2. BACKGROUND ON EGYPT'S AGRICULTURE

Agriculture is an important part of the Egyptian economy, making up around 12 percent of the country's GDP. Although employment in agriculture has been declining, the sector still provides employment for about 30 percent of the population and contributes to a relatively low and stable food import dependency of around 15 percent (El-Enbaby et al. 2016). Egypt's agricultural sector is characterized by high land productivity, high crop yields, and high cropping intensity, which is estimated at 172 percent, as three cropping seasons are utilized under irrigated production annually (Abdel Meguid 2017).

The sector saw significant yield and production gains between 1965 and 2005 due to increases in cropping intensity, agricultural productivity, and land expansion (El-Enbaby et al. 2016; McCarl et al. 2015). However, yields have stagnated in the past decade and some inefficiencies plague the system, including increasing soil salinity and low water use efficiency, which hinder additional productivity gains and prospects of sustainable agricultural growth. Moreover, farm incomes have stagnated, and 30 percent of rural residents are living in poverty, especially in Upper Egypt, where two-thirds of the extreme poor live (El-Enbaby et al. 2016).

Around 95 percent of the Egyptian population live in the Nile Valley and Delta, a long strip of fertile land making up less than 5 percent of the land area that is otherwise desert. Egypt can be divided into four main geographical areas: the Nile Valley and Delta, where most of the country's population live and most agricultural production takes place; the Western Desert; the Eastern Desert, and Sinai. The Nile Valley and Delta area can be divided Lower and Upper Egypt. Lower Egypt is in the north and includes the Delta, where the most fertile lands are concentrated and cultivated, and the metropolitan areas of Cairo and Alexandria. Upper Egypt in the south consists of a fertile strip of agricultural land extending south along the Nile Valley to the Aswan High Dam and its Lake Nasser reservoir. The Nile Valley and Delta area comprise agricultural "Old Lands", which have been cultivated for thousands of years and make up around 85 percent of the cropped area, mostly cultivated by smallholders. The other 15 percent represent "New Lands" or newly "reclaimed lands" with a mix of small farmers and large commercial farms utilizing capital-intensive agricultural technologies farm arable land that was previously desert (El-Enbaby et al. 2016; McCarl et al. 2015). Production in the reclaimed lands is growing, but currently contributes less than 10 percent of the value of agricultural production (El-Ramady et al. 2013).

Typically, the agricultural production unit in Egypt is the small family farm of less than a hectare, and sometimes just around one acre. Collectively, such farms form the backbone of food production in Egypt. Commonly, rural families are involved in crop and livestock production, and also participate in farm and non-farm labor markets (Ghanem 2014). Many of them practice subsistence farming, selling any surplus on the market. Although crop yields and production increased significantly over the past four decades, recent stagnation in yield growth, coupled with the threats climate change and a growing population relative to the restricted natural resource base, pose threats to Egyptian farmers and their livelihoods, particularly those most dependent on agriculture for their income.

Cropping patterns have not changed significantly over the years. In winter, the main traditional crops are wheat and clover, while in summer, maize and sorghum (subsistence crops), as well as rice and cotton (cash crops) are the major crop produced (Ouda and Zohry 2015). Rice is only grown in Lower Egypt, while in Upper Egypt, perennial sugarcane is grown. The typical crop rotation is a three-year cycle, involving clover, a legume forage crop, in winter, followed by a cereal crop in summer, such as maize, as well as a fiber crop, likely cotton, followed again by a cereal crop, possibly wheat, and clover, and so on (ibid.). Cereals consistently make up the largest category of production

(El-Enbaby et al. 2016). Agricultural policies, particularly those encouraging cereal production, played an important role in establishing the current mix of agriculture production.

Historically under a command economy, since 1980 agricultural policy in Egypt shifted focus to liberalization of the sector (Ibrahim and Ibrahim 2003). Farm gate price controls, subsidies, and external trade restrictions were removed, and farmers were left to choose what crops to grow, except for rice, the area and location of which is still restricted by government to parts of the Nile Delta and Fayoum (Fahmy et al. 2000; Ibrahim and Ibrahim 2003; Gouda 2016). This is due to the high water requirements of rice. Yet due to its profitability, rice planting is popular, so this restriction is sometimes violated.

The Egyptian government also adopted a policy of self-sufficiency for the country's staple foods, especially wheat. Farmers receive a quota of subsidized fertilizer, according to the size of their land and the crop they plan to produce. However, by restricting the subsidy to nitrogen-based fertilizers, in practice the quota system tends to favor wheat cultivation over other crops. Fertilizer subsidies together with price controls in wheat markets (Kassam and Dhehibi 2016) have contributed to the reduction of the area cultivated with cotton in favor of food crops. Once a major strategic crop, the area under cotton dropped from 2 million feddans[1] in the 1960s to only 0.7 million feddans in 2001 (Ibrahim and Ibrahim 2003). Similarly, the cultivated area of fava beans has also declined, as the nitrogen cycle benefits of fava beans are now substituted for with inorganic fertilizer application. Some argue that reforming Egypt's fertilizer subsidy system would result in a more diversified crop mix (Kassam and Dhehibi 2016). In addition, the fertilizer subsidy distribution system often does not work well and lacks supervision, thus farmers often have to refer to the vagaries of the black market when purchasing fertilizer beyond their quota amount (Ghoneim 2012; Elgerzawy 2014). Nevertheless, the increase in clover area and its growing popularity can partially be explained by the soil conservation and soil quality benefits it offers farmers (Ouda and Zohry 2015). Farmers commonly grow clover between seasons as the main feed for livestock, but also to enrich the soil, maintain fertility, and increase the yields and quality of cereals planted afterwards without as much need for fertilizer (Dost et al. 2014).

Some inefficiencies in the sector hinder additional productivity gains and prospects of sustainable agricultural growth. For example, around 35 percent of agricultural land suffers from high levels of salinity. The main causes in Egypt are poor soil and water management, poor drainage, and salt-water intrusion from the Mediterranean Sea. The Nile Delta is where most of the salt-affected soils are located (ICARDA 2011). Further, although the construction of the Aswan High Dam in 1967 marked the start of a great leap in agricultural productivity and intensification in Egypt, a negative side effect was preventing a significant amount of silt from flowing down the Nile to fertilize the lands downstream. This too has contributed to decreasing soil quality. Consequently, fertilizer use, particularly nitrogen fertilizer, has more than tripled in the three decades between 1968/69 and 1998/99 and continues to rise. Increased fertilizer use, in turn, contributes to salinization.

There is also room for improvements in farm-level irrigation and drainage, as poor water and soil management are among the factors negatively affecting the productivity of land and the sustainability of resource use. Water use efficiency at the farm level is estimated to be as low as 50 percent (Mahmoud and El-Bably 2017; ICARDA 2011). In addition, Egyptian agriculture is characterized by high land fragmentation, a feature that is increasing because of land-dividing inheritance laws and demographic pressure. It is estimated that 96 percent of landholdings in the

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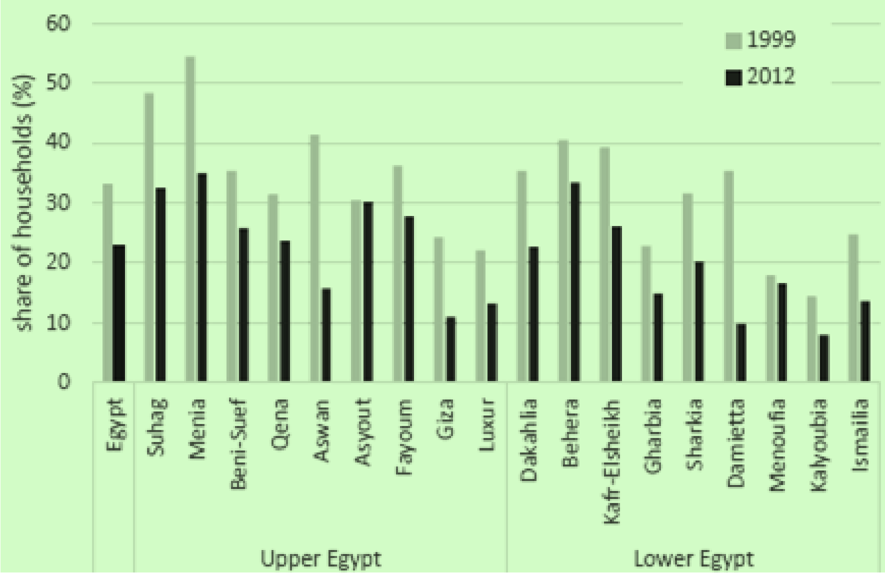
[1] A feddan is a widely used land measurement unit in Egypt, equivalent to about 0.42 hectares

Old Lands are less than 5 feddan (El-Enbaby et al. 2016). This results in low technical efficiency, poor farmer access to markets, and prevents farmers from benefitting from economies of scale (Abou-Ali and Kheir-El-Din 2010). In addition, the small land plots result in about 12 percent of fertile agricultural land being lost to boundary separations (Ghanem 2014), further contributing to stagnation in farmers' incomes.

The agricultural sector in Egypt has had a limited role in reducing poverty compared to the industrial and services sectors. This is one of the reasons that households are moving out of agriculture, as can be seen in Figure 2.1. Only between 18 and 24 percent of households are exclusively employed in agriculture, depending on the region (El-Enbaby et al. 2016). Such households tend to have less income generation capacity and rely on informal channels and lower added value activities. Upper Egypt, where two thirds of the extreme poor live, has lagged in development compared to Lower Egypt, where there are more industries and, thus, access to non-farm jobs (Ghanem 2014; Smith et al. 2013). While 22 percent of the population live under the poverty line, rural poverty is 30 percent, and rural population lags in access to services compared to urban areas (Ghanem 2014).

Figure 2.1. Proportion of agriculture-only households in total number of households



Source: El-Enbaby et al., 2016

3. DATA SOURCES

To build a comprehensive dataset of agricultural households, we combine data from different sources. First, to take stock of the current picture of agriculture production, we utilize national statistics related to crop areas, production, yields, water use, input use, and costs. Specifically, we draw on governorate-level statistics from annual bulletins published by the Economic Sector of the Ministry of Agriculture and Land Reclamation (MoALR) and by the Central Agency for Public Mobilization and Statistics (CAPMAS): The *Bulletin of Agricultural Statistics (2013/2014) (*MoALR 2015a), the *Statistical Bulletin of Cost of Production and Net Return (2013/2014)* (MoALR 2015b), and the *Annual Bulletin of Irrigation and Water Resources (2014) (*CAPMAS 2014).[2] The bulletins

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[2] It was not feasible to obtain the full data for the 2012 bulletins; the 2014 bulletins were the most complete sets of data available to the research team and the closest to 2012 for comparison with ELMPS data.

contain detailed information on outputs and costs of fertilizer, pesticide, irrigation, labor, machinery and other inputs per feddan for about 80 major crops disaggregated by governorate and season.

Household-level data is obtained from the 2012 round of the Egyptian Labor Market Panel Survey (ELMPS) conducted by the Economic Research Forum (OAMDI 2016). The full nationally representative sample includes information on employment, education, earnings and assets for 49,186 individuals in 12,060 households (Assaad and Krafft 2013). In addition, and most relevant for this study, the survey includes an agriculture module with information on household land and livestock ownership, crop areas, volume, and value of production for sale and own consumption, as well as agricultural assets. Of the 12,060 households in the sample, about 2,000 households obtain a share of their total income from farming.

Despite the detailed information that the ELMPS provides at the household level, this dataset has three major limitations for this study. First, it does not include information on input use and prices. Second, the survey is nationally representative of the labor market, but it is not representative of the agriculture sector. Finally, the survey does not include border governorates, which are those governorates also relying on groundwater for irrigation. In what follows we describe how we combine information from ELMPS and CAPMAS (2014) to overcome these data limitations and obtain a complete dataset for the analysis of agricultural household income and production.

One of the challenges of data harmonization was with unit conversions to match datasets. Specifically, CAPMAS/MoALR crop production is recorded in tons, whereas in the household survey, options for reporting also included other units like *qintar*, *ardab*, and *qirat*, where the first two are volumetric units and the last is a land area measure. Conversions to tons, as per MoALR conversion standards were calculated for specific crops that are usually reported in these different measures, including *qintar* for onion and cotton and *ardab* for various grains and some legumes. However, for the limited household cases reporting some crops for which no conversion information was available, yields in different units were compared with average yields in tons from CAPMAS/MoALR data in the particular governorate to obtain an approximation of the conversion coefficient for the crop in question. FAO estimates for crop yields were also used for verification.

Data on crop and livestock revenues was available for most households. National crop prices obtained from MoALR were substituted in entries where crop revenues were not available in the survey, or when errors in production unit conversions resulted in selling price distortions for certain households. In a few cases, national crop prices were obtained from FAOSTAT.

To obtain farm labor data, we estimated labor hours based on the number of household members working in the family farm (family labor), as well as the agriculture workers reported as being hired by the household farm. We adjusted the number of workers according to time allocation, taking into consideration secondary jobs. To estimate non-farm income and dependency on agriculture from the household's own farm, we combine income from wages, received pensions and remittances, and non-agriculture profits. The cost of hired labor for household farms was estimated based on an average 84 labor-days per year, on the basis of 80 EGP per day (Mohamed et al. 2008). Similarly, since the survey does not contain data on fertilizer use and other materials, we calculated the shares of fertilizer and materials costs over the total crop revenue to compute the needed coefficients.

The amount of water used for irrigation per crop was obtained from a separate bulletin to the crop production and area bulletins. Irrigation data is for the total of the crop area per governorate (as opposed to water use per feddan). Moreover, available fruit tree irrigation data was not disaggregated by governorate or region. Therefore, we use supplementary crop water requirements data per governorate, taking into consideration differences in crop evapotranspiration rates across different regions and seasons (El-Shirbeny et al. 2014).

4. METHODOLOGY

We follow Dorward (2002) who argues that a household classification scheme based on resource and environmental variables is most likely to capture household behavior, as the groups of activities in which households engage are determined by the sets of constraints and possibilities that result from their resources and the economic environment in which they operate. This means that households engaged in similar activities do not necessarily show similar behavior because this engagement may derive from very different sets of resources and environments. Although the causality runs from resources and the environment to activities, one would expect a relationship exists between resources and environmental variables on the one hand, and activity and welfare variables on the other (ibid.). Some of the desirable properties for a typology to be useful for policy analysis are, according to Dorward (2002), that it should not generate an unmanageable number of types to include in models; that it should relate to 'variables of interest' for policy and other scenario modeling; and that it should be linked to differences between geographical areas.

To model farm typologies in Egypt, we applied a multi-step procedure that includes cluster analysis similar to the procedure followed by previous studies, e.g., Briggeman et al. 2007; Huynh et al. 2014. The steps in the analysis are as follows:

- Identify variables for use in cluster analysis;
- Standardize selected variables and check for outliers;
- Investigate patterns of variation with different numbers of clusters and different variables; and
- Interpret cluster results, reclassify households, and construct the typology.

Identification of the variables includes the use of principal components analysis (PCA) to solve multicollinearity problems and to reduce the number of relevant variables in the dataset. Then, using selected variables based on the PCA results, we applied cluster analysis to obtain a first classification of households into representative groups. As highlighted by Dorward (2002, p. 5):

> "[I]t is important to note that the household classification that results from the proposed procedure is in many ways an artifact of the analyst's choice and weighting of variables and its task is to provide a meaningful and operational 'dissection' of a mass of households that differ across many continuous variables, and where the task of the analyst is to choose appropriate variables to achieve this dissection. Interpretation of results and eventually regrouping household between groups that result from the cluster analysis is a key step to define the final classification system."

Identification and standardization of variables

Evidence from the literature suggests that in order to identify distinct behavioral patterns, the appropriate typology must sort different farm households in a way that maximizes the degree of association between households while capturing the heterogeneity of different household behaviors in order to organize farm households into meaningful and mutually exclusive groups. Two major groups of variables are relevant to build a typology that reflects household behavior and is policy-relevant:

- environmental or location variables related to agro-ecological variation and geographic location, including natural resources and elements in the economic environment, such as access to higher earning off-farm income sources; and
- resources and factors of production, like access to land, labor and capital, including both productive assets and working capital to support seasonal investment in inputs (Dorward 2002).

Environmental and location variables

We focus on the Nile Valley and Delta where 95 percent of the Egyptian population live and most agriculture production takes place. We divide this main agricultural region into two regions: 1) Lower Egypt, including the Delta, where the most fertile lands are concentrated and cultivated, and the major metropolitan areas of Cairo and Alexandria are located; and 2) Upper Egypt, a fertile strip of agricultural land extending towards the south along the Nile Valley.

Despite the apparently homogenous agroecological conditions in the desert and along the Nile Valley, there are some agroecological differences between Upper and Lower Egypt that need to be captured in a typology. The most important of these is temperature and evapotranspiration, both of which are significantly higher in Upper Egypt. These climate factors have consequences on water demand and determine the different crop mixes between regions.

The two regions also are associated with different economic environments and access to markets. Table 4.1 shows the distribution of Egypt's population across regions. Only 33 percent of the total population and 17 percent of the urban population is in Upper Egypt. The population structure of the two regions has obvious consequences for employment opportunities.

Table 4.1. Rural and urban distribution of households and population, by region, percent share

	Households			Population		
	Rural	**Urban**	**Total**	**Rural**	**Urban**	**Total**
Lower Egypt	59	85	71	55	83	67
Greater Cairo	-	*44*	*20*	-	*42*	*18*
Alexandria and Suez Canal	-	*18*	*8*	-	*18*	*8*
Lower Egypt other	*59*	*23*	*42*	*55*	*23*	*41*
Upper Egypt	41	15	29	45	17	33

Source: Elaborated by authors based on ELPMS

Table 4.2 shows the distribution of workers in Egypt, distinguishing between agricultural and non-agricultural and between hired and self-employed workers. Notice that the total number of workers in Upper Egypt is proportional to the population with 33 percent of total population and 32 percent of total workers. However, there are differences in the structure of employment between regions. In Lower Egypt, about 75 percent of employment is non-agricultural, while that number is closer to 50 percent in Upper Egypt. These differences are explained by higher urbanization in Lower Egypt given that in rural areas, the proportion of total workers who are non-agricultural is the same in both regions.

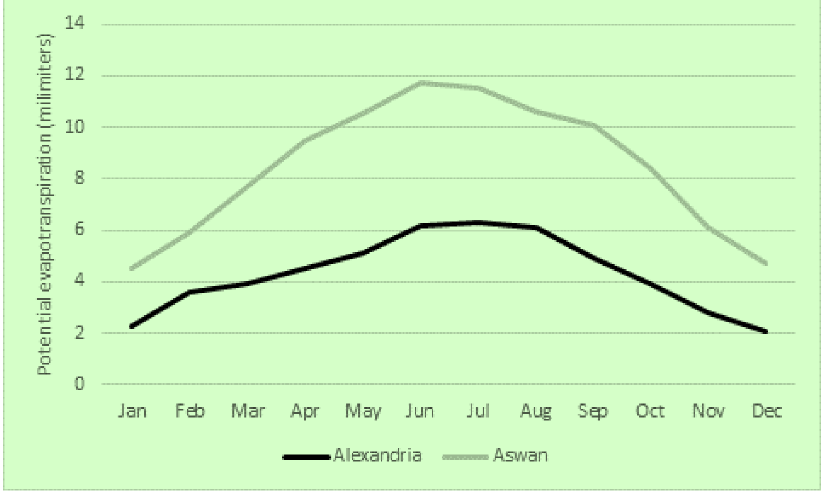
Table 4.2. Number of workers in agriculture and non-agriculture by region

	Working in agriculture			Working in non-agriculture			
	Family workers	Hired workers	Total	Family workers	Hired workers	Total	Total
Number, thousands							
Lower Egypt - Metro	161	164	325	1,094	5,037	6,131	6,456
Lower Egypt - Urban	269	77	346	566	1,671	2,236	2,582
Lower Egypt - Rural	3,520	816	4,337	1,271	4,322	5,593	9,930
Sub-total Lower Egypt	3,950	1,058	5,008	2,931	11,029	13,960	18,968
Upper Egypt - Urban	290	102	392	316	1,210	1,526	1,918
Upper Egypt - Rural	2,658	832	3,490	823	2,667	3,490	6,980
Sub-total Upper Egypt	2,948	934	3,882	1,139	3,877	5,016	8,898
Total	6,898	1,992	8,890	4,070	14,907	18,976	27,867
Distribution, percentage							
Lower Egypt - Metro	2	8	4	27	34	32	23
Lower Egypt - Urban	4	4	4	14	11	12	9
Lower Egypt - Rural	51	41	49	31	29	29	36
Sub-total Lower Egypt	57	53	56	72	74	74	68
Upper Egypt - Urban	4	5	4	8	8	8	7
Upper Egypt - Rural	39	42	39	20	18	18	25
Sub-total Upper Egypt	43	47	44	28	26	26	32
Total	100	100	100	100	100	100	100

Source: Elaborated by authors based on ELPMS

The environment for agricultural production is also different between the two regions, mostly due to higher temperatures in Upper Egypt, which results in higher water demand for irrigation. Figure 4.1 compares potential evapotranspiration for a standard species in Alexandria in Lower Egypt with Aswan in Upper Egypt. Evapotranspiration is twice as high in Aswan than in Alexandria. Evapotranspiration is higher in Upper Egypt as the result of higher solar radiation and air temperature and lower relative humidity (El-Shirbeny, Ali and Saleh 2014).

Figure 4.1. Potential evapotranspiration for Alexandria and Aswan, mm/day



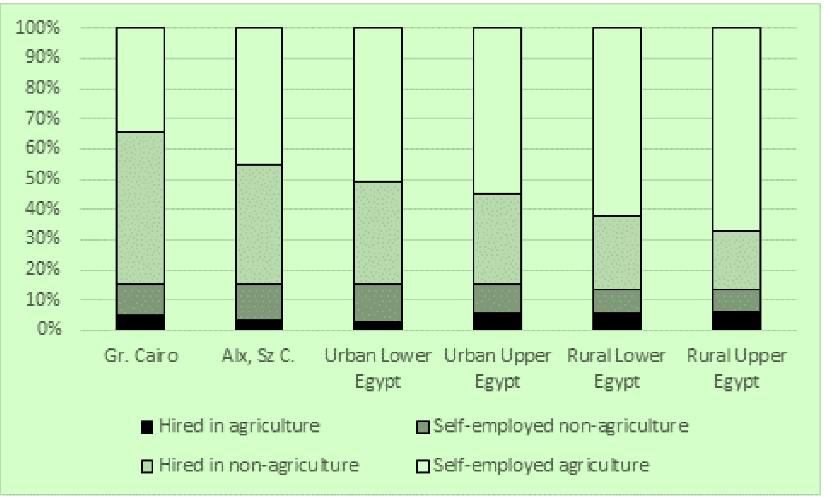
Source: El-Shirbeny, Ali and Saleh 2014

Labor

Allocation of labor by the operator to farm or off-farm work is one of the main economic decisions of the household. Household members will work on the farm if the marginal value of farm labor exceeds the off-farm wage and vice versa. Location and access to labor markets plays a major role in determining the opportunity cost of labor.

Figure 4.2 shows the structure of employment of an average household from different regions in Upper and Lower Egypt. Among households engaged in any agriculture, we observe that in metropolitan areas only 30 percent of working hours go to agricultural production on their own farm. In contrast, 70 percent of family working hours in rural Upper Egypt are spent on the farm. Income diversification is higher in urban areas and in Lower Egypt compared to Upper Egypt.

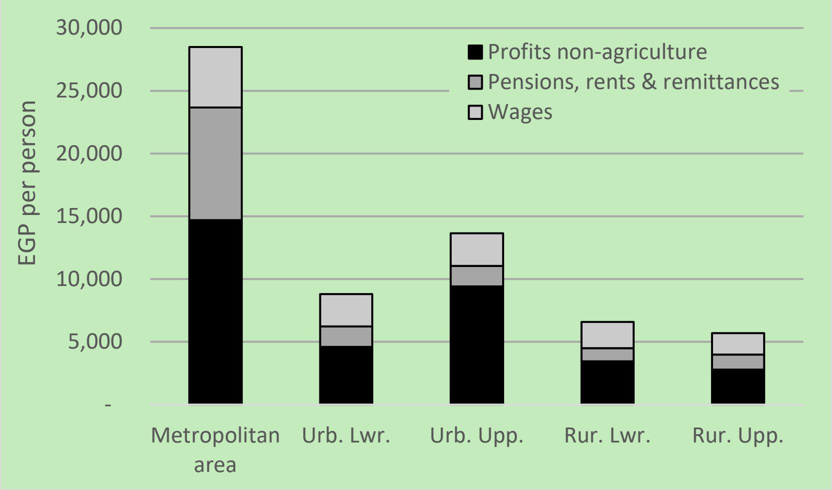
Figure 4.2. Structure of employment of household members from an average household in different regions, percentage of total hours worked by all family workers



Source: Elaborated by authors based on ELMPS.

Opportunities for diversifying income are also higher in urban areas and in Lower Egypt where the major urban developments are located. Figure 4.3 shows that urban agricultural producers in metropolitan areas receive on average nearly 30,000 EGP as non-farm income. This compares with 5,700 EGP for farmers in rural Upper Egypt and 6,600 EGP for farmers in rural Lower Egypt. Notice that urban farmers in Upper Egypt receive much higher non-farm income than all other farmers at 15,000 EGP, except for farmers in metropolitan areas.

Figure 4.3. Non-farm income received by farmers in different regions, EGP per person

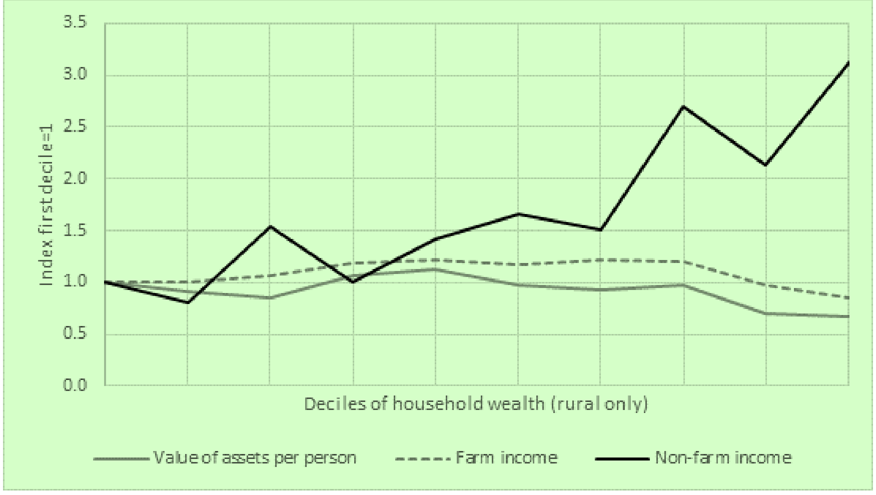


Source: Elaborated by authors based on ELMPS.

Wealth

For constructing the household typology, household wealth is measured as asset accumulation. These assets affect the production of agricultural goods, the returns from non-farm investments, and the borrowing ability of a farm household through collateral availability (Andersen et al. 2006). In the case of Egypt, household data from ELMPS show that the wealth of rural agricultural producers is highly correlated with non-farm income. Wealth is not related to revenue from agricultural production nor to the value of assets per person, although there seems to be a correlation between revenue and household assets. This confirms the importance of non-farm income for agricultural producers in Egypt's rural areas.

Figure 4.4. Value of assets, farm and non-farm income by decile of rural household wealth for households producing agriculture



Source: Elaborated by authors based on ELMPS

Input mix and production intensity

Andersen (2006) argues that farm size is an important dimension of both economic and social aspects of farming. In many cases, farms of different sizes react differently to policy measures or market changes[3]. Most importantly, farm size is correlated with relative availability of labor, land, and capital, which determine production possibilities, production intensity, and different behaviors in decision making.

The percentage of households in Lower and Upper Egypt per quintile of farm area is presented in Figure 4.5. Most households in Egypt work very small farm areas of less than a feddan. This is the case of 60 percent of households in Lower Egypt and more than 70 percent of households in Upper Egypt. 25 percent of households work on 1 to 2 feddans in both regions and close to 10 percent of households have areas between 2 and 3 feddans in Lower Egypt. In Upper Egypt, less than 10 percent of households have farm areas bigger than 2 feddans.

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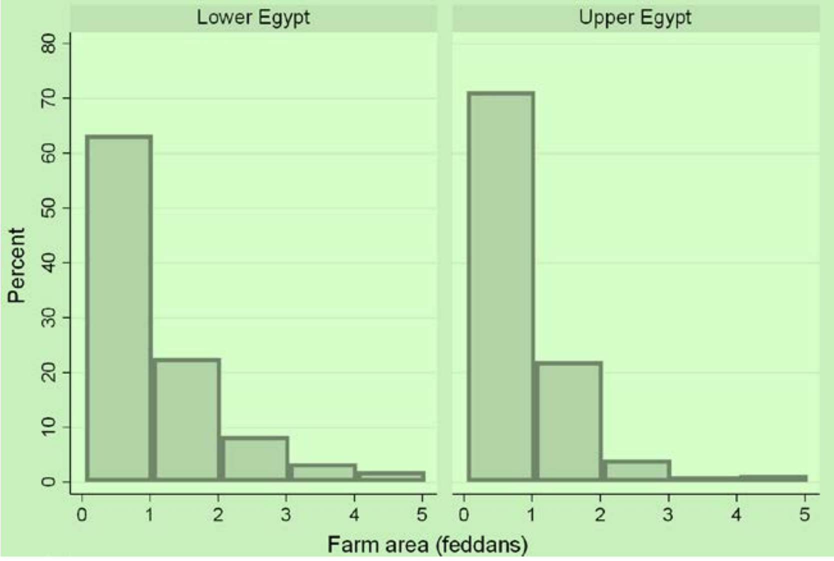
[3] The size of farming does not refer necessarily to farm area but can be measured in different ways: total number of hectares, herd size in livestock units or heads, value of output, among others depending on the comparison at hand.

Figure 4.5. Distribution of households by farm area, by region



Source: Elaborated by authors based on ELMPS

Table 4.3 presents average values of input mix indicators and partial productivity by farm size quintile. Income is correlated with area but income for households in quintile 5, the largest land area quintile, is less than twice the income of smaller farmers, while farm area is 20 times bigger at 3.8 compared to 0.2 feddans. The value of assets per person doubles in each quintile with respect to the previous quintile going from 4,700 EGP to 57,000 EGP. As expected, revenue per feddan is highest among farmers in quintile 1 and smallest in quintile 5 – 18,500 and 6,200 EGP per feddan, respectively – while the opposite is true for revenue per worker – 2,900 and 11,300 EGP, respectively. Cropping intensity as measured by the ratio of harvested to cultivated area annually is highest in quintile 1 and is a consequence of the large number of workers per feddan, 9.0. In contrast, household in quintile 5 have only 1.2 workers per feddan. Thirty percent of the work force among farmers in quintile 1 are hired workers. This is related to the importance of off-farm income among small farmers. The higher labor productivity of larger farms is the result of a different mix of inputs, as these farms use higher levels of capital per worker.

Table 4.3. Input combinations by quintile of farm size, country averages

	Quintiles of farm area				
	1	**2**	**3**	**4**	**5**
Farm area, feddan	0.2	0.5	0.9	1.7	3.8
Income per person, EGP	3,410	4,261	4,697	5,029	6,075
Value of assets per person, EGP	4,722	8,517	15,203	26,328	56,990
Share of agriculture in income, %	40	50	63	73	83
Revenue/feddan, EGP	18,487	13,592	13,721	9,693	6,205
Revenue/worker, EGP	2,947	4,451	6,958	8,264	11,324
Ratio of harvested to cultivated area	3.9	2.8	2.9	1.9	1.6
Worker per feddan	9.0	4.5	3.2	1.9	1.2
Hired workers as a share of family labor	0.3	0.2	0.5	0.5	1.0
Capital per worker, EGP	4,792	6,498	6,754	8,245	9,929
Capital machinery per worker, EGP	849	1,155	1,391	1,636	2,505
Capital livestock per worker	3,943	5,236	5,343	6,538	6,701
Water for irrigation/m^2, m^3	0.86	0.86	0.91	0.95	0.95

Source: Elaborated by authors based on ELMPS

Input combinations for households in the same quintile of farm area is similar between regions (Table 4.4). Notice that differences in income between quintiles are very small in Lower Egypt, but relatively large in Upper Egypt. This is likely related to income diversification, which is higher in Lower Egypt for all quintiles. The use of machinery is low in Upper Egypt (quintiles 1 to 3), but animal stocks are higher.

Table 4.4. Input combinations by quintile of farm size, regional averages

	Quintiles of farm area				
	1	**2**	**3**	**4**	**5**
Lower Egypt					
Farm area, feddan	0.2	0.5	0.9	1.8	3.8
Income per person, EGP	4,359	4,946	4,971	5,336	5,711
Share of agriculture in income, %	31	43	56	69	82
Revenue/feddan, EGP	14,929	12,418	11,093	7,438	5,055
Revenue/worker, EGP	2,434	4,254	6,529	6,824	11,284
Ratio of harvested to cultivated area	4.3	3.4	2.6	1.8	1.6
Worker per feddan	8.7	4.5	3.1	1.7	1.2
Hired workers as a share of family labor	0.1	0.3	0.6	0.6	1.2
Capital per worker, EGP	5,025	7,579	6,343	8,741	9,728
Capital machinery per worker, EGP	1,373	1,568	2,072	1,953	2,463
Capital livestock per worker	3,652	5,927	4,223	6,755	7,070
Water for irrigation/m^2, m^3	0.8	0.8	0.8	0.9	0.9
Upper Egypt					
Farm area, feddan	0.2	0.5	0.9	1.6	3.7
Income per person, EGP	2,665	3,576	4,493	4,735	6,803
Share of agriculture in income, %	47	57	68	77	84
Revenue/feddan, EGP	21,282	14,765	15,673	11,849	8,507
Revenue/worker, EGP	3,353	4,650	7,283	9,610	11,407
Ratio of harvested to cultivated area	3.6	2.3	3.1	2.0	1.7
Worker per feddan	9.2	4.5	3.2	2.1	1.2
Hired workers as a share of family labor	0.4	0.2	0.5	0.4	0.5
Capital per worker, EGP	4,609	5,408	7,065	7,781	10,337
Capital machinery per worker, EGP	437	739	876	1,340	2,590
Capital livestock per worker	4,172	4,541	6,188	6,336	5,948
Water for irrigation/m^2, m^3	0.9	0.9	1.0	1.0	1.1

Source: Elaborated by authors based on ELMPS

Fertilizer and other materials, and machinery

As discussed, the ELMPS panel household survey does not have information on fertilizer use and other materials. We use shares of costs of fertilizer and materials in total crop revenue and apply these coefficients to crop revenues of the different household types. We compare obtained fertilizer quantities with recommended values of fertilizer for individual crops (FAO 2005) and adjust quantities around recommended values depending on crop revenue. Cost of machinery was calculated using value of capital in tools and machinery complemented by cost of machinery from CAPMAS. For example, if costs from own capital were higher than those from CAPMAS, we assign own costs as machinery costs.

Variables for cluster analysis

As discussed, classifying households by the activities they are involved in is not the preferred way to group households based on similar expected behavior. In our analysis, we only introduce a general distinction between production systems based on field crops (cereals, oilseeds, pulses, and industrial crops, like sugarcane) and those producing high-value crops (fruits, vegetables, garlic, onion, potato, and tomato) after households are classified by resource use and availability. This is because, even if no difference in behavior is observed between farmers producing high-value crops and other farmers, it is of interest to look at the impact of different shocks on households producing field and high-value crops. Differences in results between high-value and other systems could have implications for policy, water use, and the environment. The variables in Table 4.6, extracted or built using data from ELMPS, were selected as relevant indicators to identify households with similar behavior in decision making.

Before proceeding with the analysis, all variables were standardized. Standardization before applying the clustering algorithm leads to better quality, efficient, and accurate cluster results. The optimal standardization procedure depends on the nature of the datasets for the analysis. Mohammad and Usman (2013) show that the Z-score is the standardization method that results in the more accurate and efficient result in a k-means clustering algorithm. The Z-score is a form of standardization used for transforming normal variants to standard score form. Given a set of raw data *x*, the Z-score standardization formula is defined as:

$$Z(x_{ij}) = \frac{x_{ij} - \bar{x}_j}{\sigma_j}$$

where, $\bar{x}_j$ and σ_j are the sample mean and standard deviation of the jth attribute, respectively. The transformed variable will have a mean of 0 and a variance of 1. Households showing standardized variable values of greater than 3.5 were marked as outliers.

Principal Component Analysis

To prepare the data for cluster analysis, PCA analysis was applied to the selected variables. This procedure is beneficial because it reveals the structure of the variables in the dataset, reduces the number of variables to a set of uncorrelated variables or factors, and avoids implicitly overweighting certain characteristics represented simultaneously by several variables (Huynh et al. 2014; Dolnicar 2002). Table 4.5 presents the results of the PCA. Eight components show an eigenvalue greater than 1, the critical value to determine the number of relevant components. These eight components explain 76 percent of the total variation of the 21 variables considered in the analysis (last column in the first part of Table 4.6).

Table 4.5. Results of Principal Components Analysis

Component	Eigenvalue	Difference	Proportion of variation explained	Cumulative
Comp 1	3.26	0.61	0.16	0.16
Comp 2	2.64	0.39	0.13	0.30
Comp 3	2.26	0.25	0.11	0.41
Comp 4	2.01	0.50	0.10	0.51
Comp 5	1.51	0.18	0.08	0.58
Comp 6	1.33	0.20	0.07	0.65
Comp 7	1.13	0.08	0.06	0.71
Comp 8	1.05	0.21	0.05	0.76
Comp 9	0.84	0.04	0.04	0.80
Comp 10	0.80	0.14	0.04	0.84

Source: Elaborated by authors

Table 4.6. Correlation between variables used in cluster analysis to identify household types

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Age of household head	**1**	1.00																				
Household size	**2**	-0.46	1.00																			
Share of agriculture in income	**3**	-0.05	-0.07	1.00																		
Income per capita	**4**	0.27	-0.26	-0.24	1.00																	
Farm area	**5**	0.03	0.12	0.39	0.19	1.00																
Workers in agriculture / household size	**6**	0.34	-0.33	0.29	0.05	0.12	1.00															
Hired workers	**7**	0.00	0.09	0.31	-0.07	0.30	0.23	1.00														
Stock of cattle	**8**	-0.04	0.15	0.30	0.06	0.33	0.21	0.22	1.00													
Workers/feddan	**9**	-0.03	0.06	-0.08	-0.27	-0.43	0.32	0.13	-0.08	1.00												
Hired/family workers	**10**	0.02	-0.03	0.26	-0.05	0.23	0.02	0.82	0.10	0.06	1.00											
Capital/worker	**11**	0.00	-0.03	0.02	0.16	0.10	-0.20	-0.19	0.51	-0.28	-0.14	1.00										
Value of assets per person	**12**	0.35	-0.35	0.35	0.33	0.71	0.33	0.18	0.31	-0.37	0.19	0.20	1.00									
Machinery/feddan	**13**	-0.03	0.01	-0.05	0.00	-0.12	0.00	-0.02	0.07	0.12	-0.02	0.20	-0.06	1.00								
Machinery/worker	**14**	-0.01	-0.01	0.00	0.12	0.07	-0.10	-0.08	0.12	-0.17	-0.06	0.51	0.14	0.48	1.00							
Animal stock/feddan	**15**	-0.03	0.04	-0.05	-0.11	-0.29	0.07	-0.05	0.42	0.38	-0.07	0.40	-0.18	0.19	0.02	1.00						
Revenue/worker	**16**	-0.06	0.04	0.19	0.42	0.33	-0.31	-0.19	0.13	-0.44	-0.13	0.44	0.24	-0.05	0.20	-0.12	1.00					
Revenue/feddan	**17**	-0.11	-0.01	0.13	0.13	-0.18	-0.02	-0.06	-0.10	0.09	-0.04	-0.11	-0.15	0.00	-0.06	-0.09	0.20	1.00				
Cropping intensity	**18**	0.02	0.04	0.16	0.20	0.10	0.05	0.07	0.01	-0.09	0.07	-0.02	0.06	-0.18	0.06	-0.12	0.25	-0.22	1.00			
Crop/livestock revenue	**19**	-0.02	-0.03	0.07	0.06	0.12	-0.01	0.06	-0.22	-0.08	0.05	-0.19	0.08	-0.09	-0.06	-0.26	0.06	0.12	0.10	1.00		
Share of high-value crops in revenue	**20**	-0.09	0.03	0.15	0.15	0.10	0.02	0.00	0.07	-0.06	0.01	0.05	0.05	-0.03	0.01	-0.04	0.24	0.32	0.06	0.06	1.00	
Water per m^2	**21**	-0.09	0.11	0.11	-0.02	-0.04	0.00	-0.02	0.16	0.04	-0.02	0.07	-0.08	0.09	0.05	0.11	0.08	0.05	0.03	-0.08	-0.02	1.00

Source: Elaborated by authors based on ELMPS

Table 4.7 shows which are the variables associated with each of the eight components in Table 4.6, or how much each variable contributes to the components. These results can also be thought of as a measure of correlation between the component and the variable. For example, the highest variable loadings for Component 1 are the value of assets and farm area, which are highly correlated with loads of 0.480 and 0.445, respectively. We can interpret this component as mainly representing farm size. Component 2 is associated to hired labor, with a load of 0.518. Loadings of variables in components 3 to 8 indicate that these components are associated with animal stock/feddan, household size, revenue/feddan, capital in machinery/feddan, and harvested/cultivated area.

Table 4.7. Principal components (eigenvectors) and loadings of variables

Variable	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5	Comp 6	Comp 7	Comp 8
Value of assets per person	**0.46**	0.10	0.02	-0.19	-0.05	-0.01	-0.21	-0.05
Hired labor	0.15	**0.43**	0.18	0.22	-0.02	0.25	0.25	-0.18
Animal stock/feddan	-0.12	-0.12	**0.48**	-0.07	0.13	-0.24	0.19	-0.07
Household size	-0.11	-0.08	0.07	**0.52**	-0.13	-0.09	0.01	0.04
Revenue/feddan	-0.05	-0.04	-0.17	0.09	**0.65**	0.12	-0.08	-0.17
Capital in machinery/feddan	-0.04	-0.17	0.28	-0.07	0.08	**0.56**	-0.09	0.22
Harvested/cultivated area	0.15	0.02	-0.12	0.07	-0.14	-0.19	**0.58**	**0.57**
Farm area	0.44	0.11	-0.03	0.16	-0.14	-0.05	-0.23	-0.05
Capital/worker	0.22	-0.40	0.31	-0.01	-0.01	-0.03	0.04	-0.07
Revenue/worker	0.31	-0.32	-0.17	0.15	0.15	-0.08	0.14	0.00
Stock of cattle	0.25	-0.05	0.44	0.10	0.07	-0.27	0.00	-0.10
Hired/family labor	0.14	0.38	0.13	0.20	-0.04	0.33	0.31	-0.28
Workers/feddan	-0.32	0.21	0.24	-0.08	0.23	-0.02	0.18	0.18
Share of farm income	0.26	0.22	0.12	0.19	0.24	-0.12	-0.27	0.33
Age of household head	0.13	0.10	-0.02	-0.52	-0.04	0.02	0.09	-0.10
Agricultural workers / HH size	0.09	0.32	0.17	-0.34	0.22	-0.14	-0.09	0.29
Capital in machinery/worker	0.15	-0.29	0.19	-0.03	-0.05	0.48	-0.01	0.31
Share of HV crops in revenue	0.11	-0.05	-0.09	0.14	0.53	-0.04	0.13	0.02
Crop/livestock revenue	0.06	0.11	-0.30	0.07	0.07	0.19	-0.06	0.28
Income per person	0.25	-0.16	-0.18	-0.25	0.12	0.07	0.43	-0.21

Source: Elaborated by authors
Note: HV = high-value; HH = household.

We conclude from the PCA that most of the variation between households can be explained by value of assets per person or farm area, a measure of the animal stock relative to the area of land, the household size, the total value of output per unit of land, i.e., land productivity, the value of machinery per feddan, and cropping intensity. We use the variable with the highest loading in each eigenvector in the subsequent cluster analysis.

Cluster analysis

The household typology was generated using a joint factor and cluster analysis similar to those in the studies of Bidogeza et al.(2009); Briggeman et al. (2007); Daskalopoulou and Petrou (2002); Huynh et al. (2014); Köbrich et al. (2003); Lopez-Ridura et al. (2018), Micha et al. (2017), Moreno-Pérez et al. (2011); and Zorom et al. (2013), among others. Cluster analysis is a method used to segment aggregate data into groups that are homogenous within group but are heterogeneous across groups. According to Briggeman et al. (2007), in the case of policy analysis, segmenting households into policy-actionable groups that are based on household economic theory allows policy makers to analyze the impact of policy on groups of farm households that are similar in how they decide to allocate their resources rather than on groups defined by farm size or farm sales. For such a typology to be useful, it must define clusters with high intra-class similarity and low inter-class similarity using criteria that are intuitive and identifiable (Briggeman 2007).

There are two general approaches in cluster analysis, approaches that use hierarchy algorithms and approaches that use partitioning algorithms.[4] Hierarchical clustering methods consist of mergers of previously formed clusters, starting with as many clusters as there are observations and ending with a single cluster containing all observations. At each step, the algorithm keeps track of the distance at which the clusters are formed. To determine the number of clusters, the algorithm considers the steps at which the merging distance is relatively large.

In contrast, partitioning methods require that the number of clusters be pre-determined. When there is no a priori information about the number of clusters, it is necessary to investigate the multivariate structure of the data or undertake a hierarchical clustering to obtain an idea of the likely number of groups. An extensively used partitioning algorithm is the k-means algorithm (MacQueen 1967). This method minimizes the average of the squared distances between the observations and their cluster centers or centroids by performing these steps:

a) Specify the number of clusters and, arbitrarily or deliberately, the members of each cluster [5];
b) Calculate each cluster's centroid, and the distances between each observation and centroid. If an observation is nearer the centroid of a cluster other than the one to which it currently belongs, re-assign it to the nearer cluster;
c) Repeat b) until all observations are nearest the centroid of the cluster to which they belong; and
d) If the number of clusters cannot be specified with confidence in advance, repeat steps a) to c) with a different number of clusters and evaluate the results.

In our analysis we use the weighted k-means clustering algorithm which conveniently maximizes the similarity between observations in a cluster, i.e., minimizing Euclidean distances. We partially follow the procedure by Briggeman et al. (2007) and validate results using the approach by Makles (2012). Starting with a fairly large number of variables, we reduced the number of variables by looking for broad patterns of stable groups, considering between 2 and 20 clusters. The process involved a search for consistent patterns of differentiation between clusters using different combinations of variables, different seeds, and different numbers of clusters (Briggeman et al. 2007). As the number of clusters is unknown, we use the approach by Makles (2012) where several k-means solutions with different numbers of groups *k (k = 1, . . . , K)* are computed and compared. To detect the clustering with the optimal number of groups $k*$ from the set of *K* solutions, Makles (2012) applies four indicators to all cluster solutions: the within sum of squares (WSS); its logarithm (log(WSS)); the η^2 coefficient, which is similar to the R^2; and the proportional reduction of error (PRE) coefficient:

$$\eta_k^2 = 1 - \frac{WSS_k}{WSS_1} = 1 - \frac{WSS_k}{TSS} \ \forall k \in K$$

---

[4] Cluster methods have been developed beyond this general classification. There are now density-based clusters, based on connectivity and density functions; grid-based clusters, based on a multiple-level granularity structure; and model-based, where a model is hypothesized for each of the clusters and the idea is to find the best fit of that model.

[5] The initial grouping into k groups could be arbitrarily set by the researcher or by randomly allocating observations to the k groups)

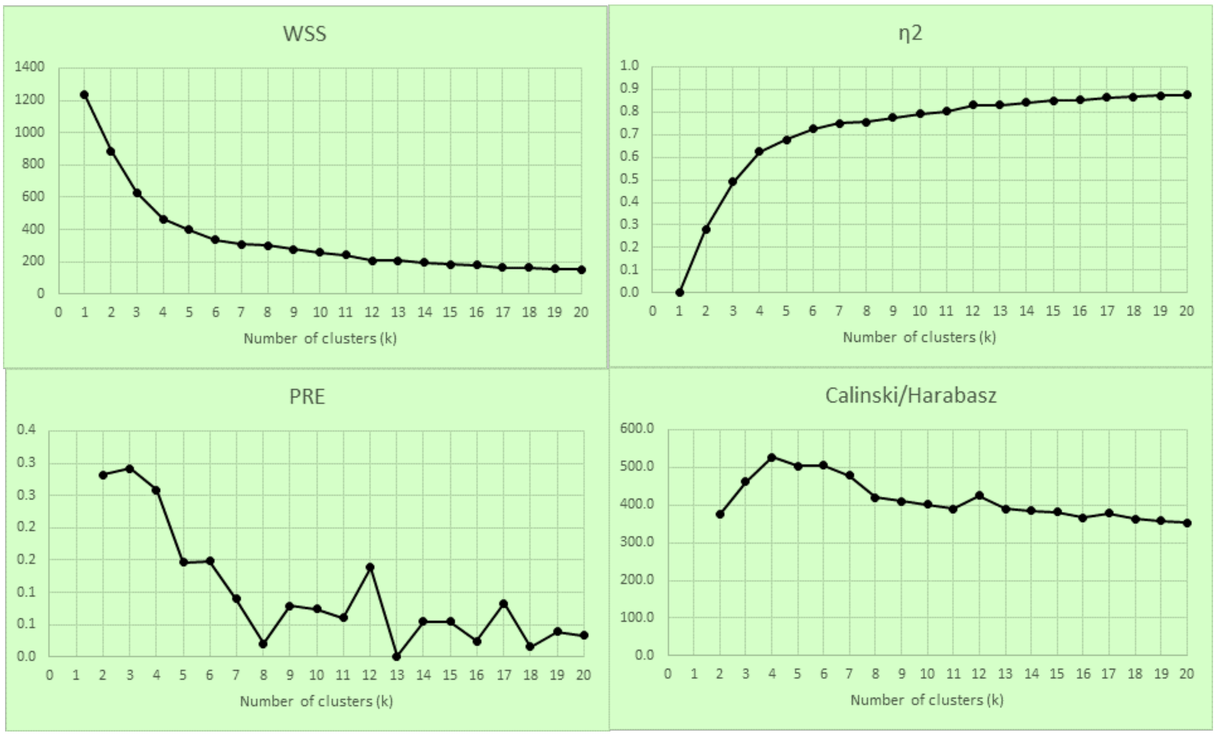
$$PRE_k = \frac{WSS_{k-1} - WSS_k}{WSS_{k-1}} \ \forall k \geq 2$$

where WSS_k is the WSS for the cluster solution *k* and WSS_1 is the WSS for the cluster solution *k=1* (non-clustered data). η_k^2 measures the proportional reduction of the WSS for each cluster solution *k* compared with the total sum of squares (TSS). Finally, PRE_k illustrates the proportional reduction of the WSS for cluster solution *k* compared with the previous solution with *k-1* clusters (Makels 2012).

We complement the indicators proposed by Makels (2012) with the Calinski-Harabasz (CH) pseudo F. This involves looking at the sum of squared distances within groups, and comparing it to that in the unpartitioned data, taking account of the number of clusters and number of cases (Halping 2016). Comparing solutions with different number of groups, the best solution is the one showing the highest CH value (Figure 4.6).

The best result of the cluster analysis was obtained using four of the seven variables selected using PCA: value of assets per person, workers per feddan, revenue per feddan, and cropping intensity, i.e., harvested area/cultivated area. The analysis show that four groups was the best result. These results were robust for different combinations of the selected variables. When the number of variables was increased to eight or more, no clear solution for an optimal number of clusters is obtained.

Figure 4.6. Indicators to identify optimal number of household clusters.



Source: Elaborated by authors
Note: WSS= within sum of squares (WSS); η2=1-(WSSk/TSS) where TSS=total sum of squares; PRE= proportional reduction of error coefficient, where PREk=(WSSk-1-WSSk)/WSSk-1

After establishing the final number of clusters, descriptive statistics of the clustering solution are analyzed and variables are tested for differences by the pairwise *t*-test statistic. If statistical significance between two groups is not found, then this is justification for combining the two groups. The candidate solutions identified were then investigated by means of their interpretability and stability. The crucial criterion in arguing that a farm type was identified is that clusters can then be meaningfully interpreted and named according to their most important and distinguishing characteristics. Results are presented in the next section.

5. HOUSEHOLD TYPES

We identified seven household types based on the overall national sample. We then divided these seven types by region (Lower and Upper Egypt) for a total of 14 household types. Table 5.1 defines the seven types according to the variables and criteria we used to identify them. The first step was to group households by relative availability of land, labor, and capital using cluster analysis. This resulted in three major groups: average producers, who are the most numerous and similar to the average household in the ELMPS survey; capitalized producers, who use high levels of capital and land per worker relative to average producers; and small producers, who have small landholdings and limited capital relative to their total available labor.

Table 5.1. Household types

Type	Type code	Description
Type 1	AVG-DI-FC	Average producer, diversified income, producing field crops,
Type 2	AVG-FI-FC	Average producer, farm income, producing field crops,
Type 3	AVG-DI-HV	Average producer, diversified income, producing high-value crops
Type 4	CAP-FI-FC	Capitalized producer, farm income, producing field crops
Type 5	CAP-FI-HV	Capitalized producer, farm income, producing high-value crops
Type 6	SML-DI-FC	Small producer, diversified income, producing field crops
Type 7	SML-FI-FC	Small producer, farm income, producing field crops

Source: Elaborated by authors

The second criterion used to group households was income diversification. As the capitalized group of households receives most of its income from agriculture, it was not subdivided by income diversification. We classified average and small households into households with diversified sources of income (non-farm income), those for whom farm income represented less than 40 percent of total income, and those depending on farm-income for more than 40 percent of their total income.

Finally, all groups were further divided depending on the importance of high-value crops in their production system. Households were separated between those producing field crops (cereals, oil crops and sugar crops) and those with at least 40 percent of their crop revenue coming from fruits, vegetables, tomato, onion, garlic, and potato. Production of high-value crops among small producers was negligible so no high-value household type was established for small producers. These households only produce field crops.

Table 5.2. Share of agricultural land, labor, capital and water for irrigation, by national farm household type

			Labor			Capital			
	House-holds	Farm area	Total	Family	Hired	Total	Animal stock	Machi-nery	Water
AVG-DI-FC	33.4	20.9	22.8	25.4	13.9	22.0	22.7	20.0	22.2
AVG-FI-FC	37.2	39.4	42.4	41.1	47.0	42.3	43.3	39.5	44.8
AVG-DI-HV	7.6	7.8	8.1	8.0	8.4	9.2	8.6	9.1	6.1
Average	78.1	68.1	73.4	74.6	69.2	73.5	74.6	68.7	73.0
CAP-FI-FC	11.6	26.7	12.2	10.4	18.5	16.7	15.8	21.3	22.3
CAP-FI-HV	1.3	2.8	1.3	1.2	1.7	2.4	2.0	3.7	2.0
Capitalized	12.9	29.5	13.5	11.6	20.3	19.1	17.8	25.0	24.3
SML-DI-FC	4.8	1.1	6.0	7.2	1.9	3.1	3.3	2.1	1.1
SML-FI-FC	4.2	1.4	7.1	6.6	8.6	4.3	4.3	4.3	1.6
Small	9.0	2.5	13.1	13.8	10.5	7.4	7.7	6.4	2.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: Elaborated by authors using ELMPS data
Note: AVG-DI-FC=Average producer, diversified income, producing field crops; AVG-FI-FCI=Average producer, farm income, producing field crops; AVG-DI-HV=Average producer, diversified income, producing high-value crops; CAP-FI-FC=Capitalized producer, farm income, producing field crops; CAP-FI-HV=Capitalized producer, farm income, producing high-value crops; SML-DI-FC=Small producer, diversified income, producing field crops; SML-FI-FC=Small producer, farm income, producing field crops.

Table 5.2 shows the importance of the different household types in terms of the number of households and their share in total farm area, labor, capital, and use of water for irrigation in our sample. The “average producer” group of households is the most numerous, representing 78 percent of households in the sample. Of these, 33 percent have diversified incomes, while 37 percent depend mostly on agriculture for their living. Their share in total labor, family labor, capital, animal stock, and water for irrigation is almost proportional to their importance in the total number of households. Capitalized households on the other hand, represent only 13 percent of total households and have a more than proportional share in total farm area (30 percent), hired labor (20 percent), machinery (25 percent), and water (24 percent). The group of small producers represents 9 percent of all households with a share of almost 14 percent of total family labor, but only 2.5 percent of total farm area.

Table 5.3. Income, wealth and importance of farm income in total income, by region and farm household type

Type	Income, EGP	Farm income, EGP	Non-farm income, EGP	Farm income as share of total, %	Assets, per capita value, EGP
Lower Egypt	19,046	8,008	11,038	48	19,923
AVG-DI-FC	23,943	4,173	19,770	17	10,487
AVG-FI-FC	13,582	9,834	3,748	72	18,184
AVG-DI-HV	23,224	11,987	11,238	52	13,903
CAP-FI-FC	18,764	14,247	4,517	76	51,220
CAP-FI-HV	23,600	18,532	5,068	79	38,305
SML-DI-FC	15,645	1,752	13,893	11	4,212
SML-FI-FC	5,805	4,928	877	85	5,885
Upper Egypt	19,035	10,744	8,291	59	12,097
AVG-DI-FC	22,467	4,333	18,135	19	6,504
AVG-FI-FC	16,602	12,776	3,826	77	11,687
AVG-DI-HV	27,132	19,590	7,542	72	13,095
CAP-FI-FC	16,560	14,114	2,446	85	51,567
CAP-FI-HV	25,676	22,936	2,741	89	54,687
SML-DI-FC	20,549	3,225	17,324	16	3,326
SML-FI-FC	6,863	5,014	1,849	73	5,102
Total	19,041	9,232	9,809	53	16,420

Source: Elaborated by authors.
Note: AVG-DI-FC=Average producer, diversified income, producing field crops; AVG-FI-FCI=Average producer, farm income, producing field crops; AVG-DI-HV=Average producer, diversified income, producing high-value crops; CAP-FI-FC=Capitalized producer, farm income, producing field crops; CAP-FI-HV=Capitalized producer, farm income, producing high-value crops; SML-DI-FC=Small producer, diversified income, producing field crops; SML-FI-FC=Small producer, farm income, producing field crops.

The income and wealth of the household types disaggregated by region are presented in Table 5.3. On average, total household income is almost identical in Lower and Upper Egypt (19,000 EGP). However, the importance of farm income in total income is higher in Upper Egypt (59 percent of total income), while households in Lower Egypt depend more on non-farm income for their living (52 percent of total income). The typology defined here separates households by importance of farm income in total income, so the differences between types are large. Those households defined as depending on farm income show a share of farm income in total income greater than 70 percent in all cases. Households with diversified income on the other hand, have a share of farm income in total income smaller than 20 percent. There is only one exception, the AVG-DI-HV group, which was mostly defined as a producer of high-value crops and not defined by the importance of farm income.

Farm income in this case is the value of agricultural production, so total income is not a good indicator of wealth. However, we use it here to determine the importance of agriculture in income. A better proxy to determine wealth of the different types is the total value of household assets divided by household size (last column in Table 5.3). Capitalized agriculture producers are the wealthier households with assets per person above 50,000 EGP, with only one exception of CAP-FI-HV in Lower Egypt. In contrast to capitalized households, small producers show value of assets per capita of 5,000 EGP or less. Also notice that the value of assets among households in Upper Egypt is 12,000 EGP, compared to almost 20,000 EGP in Lower Egypt. This difference is explained by the low value of assets in average households in Upper Egypt.

Table 5.4. Agricultural revenue, farm area, number of workers, and partial factor productivity, by region and farm household type

		Share in revenue:				Revenue (EGP) per unit of:		
Types	Revenue (EGP)	Crop (%)	Livestock (%)	Farm area (feddans)	Labor (man-equiv.)	Land (feddan)	Labor (man-equiv.)	Water (m^3)
Lower Egypt	8,008	77	23	1.2	2.2	6,694	3,506	2.8
AVG-DI-FC	4,173	75	25	0.8	1.7	5,390	2,451	2.1
AVG-FI-FC	9,834	78	22	1.3	2.6	7,476	3,829	3.1
AVG-DI-HV	11,987	91	9	1.0	2.3	11,995	5,116	6.7
CAP-FI-FC	14,247	83	17	2.6	2.5	5,394	5,768	2.6
CAP-FI-HV	18,532	87	13	1.7	2.2	10,606	8,360	5.0
SML-DI-FC	1,752	59	41	0.2	2.6	7,653	674	3.0
SML-FI-FC	4,928	54	46	0.3	3.6	14,885	1,379	4.0
Upper Egypt	10,744	68	32	1.0	2.6	10,845	4,154	3.5
AVG-DI-FC	4,333	69	31	0.6	1.5	7,560	2,897	2.3
AVG-FI-FC	12,776	70	30	1.1	2.9	11,610	4,482	3.3
AVG-DI-HV	19,590	77	23	1.2	2.6	15,927	7,411	7.6
CAP-FI-FC	14,114	74	26	2.4	2.8	5,769	5,060	2.1
CAP-FI-HV	22,936	84	16	3.1	2.5	7,373	9,168	4.2
SML-DI-FC	3,225	46	54	0.3	3.6	10,773	902	4.2
SML-FI-FC	5,014	38	62	0.4	4.3	13,025	1,175	4.8
Total	9,232	73	27	1.1	2.4	8,552	3,796	3.1

Source: Elaborated by authors

Note: AVG-DI-FC=Average producer, diversified income, producing field crops; AVG-FI-FCI=Average producer, farm income, producing field crops; AVG-DI-HV=Average producer, diversified income, producing high-value crops; CAP-FI-FC=Capitalized producer, farm income, producing field crops; CAP-FI-HV=Capitalized producer, farm income, producing high-value crops; SML-DI-FC=Small producer, diversified income, producing field crops; SML-FI-FC=Small producer, farm income, producing field crops.

Table 5.4 shows agricultural revenue, land, labor and water productivity, and average labor and land used by the seven household types at regional level. Capitalized farms producing high-value crops (HV) are the largest producers, showing the highest revenues among all types. They also show the largest land areas, with values between 2.4 and 5.1 feddans in Upper Egypt and 1.7 and 2.6 in Lower Egypt. In contrast, small producers show very small areas of between 0.2 and 0.4 feddans and revenues that are only 8 to 22 percent of those of capitalized farmers.

Land and labor productivity are related to the farm area relative to the availability of other resources and to the production system. Labor productivity is lowest among small producers. These households have the largest labor force both in absolute terms and compared to larger producers. Small producers in Upper Egypt use 3.6 and 4.3 man-equivalents, while small producers in Lower Egypt use 2.6 and 3.6 man- equivalents in agricultural production, while the average for the whole sample is 2.4. Notice that households with diversified incomes use less labor than similar farms that obtain most of their income from agricultural production, showing higher labor productivity.

On the other hand, land productivity varies significantly between types. Small producers are not necessarily the ones showing highest land productivity. Highest land productivity is observed in average farmer producing high-value crops in Upper Egypt. Some of the small producers also show high land productivity – for example, agriculture-specialized small producers. In general, specialized producers achieve higher land productivity than producers with other sources of income.

Water productivity seems to be associated to high-value crop production and area. Average producers of high-value crops and diversified incomes show the highest water productivity. Capitalized producers of high-value crops and small producers also show high water productivity.

Comparing regions, productivity on average is higher for use of land, labor, and water in Upper Egypt.

Table 5.5. Factor use and relative factor abundance, by region and farm household type

Types	Labor/land (man-equiv./ feddan)	Capital/labor (EGP/ man-equiv.)	Machinery/ labor (EGP/ man-year) *	Livestock/labor (EGP/ man-equiv.)	Cropping intensity (Harvested area/ farm area)
Lower Egypt	2.6	4,525	880	3,602	1.5
AVG-DI-FC	2.2	4,312	746	3,566	1.4
AVG-FI-FCI	2.0	4,340	921	3,419	1.7
AVG-DI-HV	2.3	4,467	274	3,108	1.5
CAP-FI-FC	0.9	6,019	1,359	4,659	1.5
CAP-FI-HV	1.3	7,411	1,995	5,417	2.0
SML-DI-FC	11.4	2,431	470	1,961	1.4
SML-FI-FC	10.8	2,554	404	2,150	2.2
Upper Egypt	3.4	4,853	842	3,991	1.7
AVG-DI-FC	2.6	4,811	771	4,040	1.4
AVG-FI-FCI	2.6	4,800	712	4,088	1.9
AVG-DI-HV	2.1	5,519	1,214	4,277	1.8
CAP-FI-FC	1.1	7,638	2,074	5,564	1.8
CAP-FI-HV	0.8	10,078	2,925	5,896	1.5
SML-DI-FC	11.9	2,302	131	2,170	1.0
SML-FI-FC	11.1	2,890	563	2,327	1.1
Total	2.9	4,672	863	3,776	1.6

Source: Elaborated by authors

Note: AVG-DI-FC=Average producer, diversified income, producing field crops; AVG-FI-FCI=Average producer, farm income, producing field crops; AVG-DI-HV=Average producer, diversified income, producing high-value crops; CAP-FI-FC=Capitalized producer, farm income, producing field crops; CAP-FI-HV=Capitalized producer, farm income, producing high-value crops; SML-DI-FC=Small producer, diversified income, producing field crops; SML-FI-FC=Small producer, farm income, producing field crops.

* Man-year refers to the amount of work performed by an average worker during one year. The number of hours worked by an individual during a year varies greatly according to cultural norms and economics. We assumed 2,000 hours per man-year.

Table 5.5 gives a better idea of the difference in the input mix and resource availability of the different household types. Average households in Lower Egypt employ about 2 workers per feddan, use capital of 4,300 EGP per worker, of which around 800 EGP are in tools and machinery and 3,500 in livestock, while the crop intensity is 1.6 (harvested/cultivated area). Comparing the average with the other two major types, we observe that capitalized farmers employ about one worker per feddan while the small producers use eleven workers per feddan. Capital per worker goes from 7,000 to 10,000 EGP in capitalized farmers, while the capital per worker for small producers is 2,500 EGP. Capitalized farmers use more than twice as much of their capital per worker in machinery than do the average types (2,000 EGP compared to 800 EGP), while small producers use less than 560 EGP per worker, with an extreme low of 131 EGP per worker in the case of households with diversified income in Upper Egypt. No clear pattern or differences between types are observed in cropping intensity with an average of 1.6 for the sample. Exception are small producers in Upper Egypt showing intensity of only 1.0, which means that they produce on average only one crop per year.

Table 5.6. Share of different crops in crop revenue, percent, by region and farm household type

Type	Wheat	Clover	Maize	Rice	Fruits	Vege-tables	Garlic, onion, potato, tomato	Sugar beet	Sugar cane	Cotton	Other
Lower Egypt	33.6	17.5	14.9	17.7	0.9	1.0	1.3	7.3	0.0	3.2	2.6
AVG-DI-FC	35.5	21.8	21.4	14.7	0.0	0.0	0.0	1.7	0.0	4.9	0.0
AVG-FI-FC	32.3	13.6	11.2	22.1	0.0	0.0	0.0	9.6	0.0	2.5	8.6
AVG-DI-HV	23.9	9.0	1.5	7.7	13.0	23.3	21.6	0.0	0.0	0.0	0.0
CAP-FI-FC	35.2	12.0	4.9	23.3	0.0	0.0	0.0	21.8	0.0	2.8	0.0
CAP-FI-HV	12.3	14.9	3.0	5.8	26.4	2.7	34.9	0.0	0.0	0.0	0.0
SML-DI-FC	29.8	30.1	32.5	7.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SML-FI-FC	43.1	23.8	14.8	18.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Upper Egypt	42.7	15.1	23.1	0.0	0.7	1.8	5.4	0.9	6.0	0.4	4.0
AVG-DI-FC	45.7	15.7	28.6	0.0	0.0	0.0	0.0	3.4	0.9	1.3	4.5
AVG-FI-FCI	45.6	15.0	21.7	0.0	0.0	0.0	0.0	0.0	11.7	0.0	6.0
AVG-DI-HV	21.7	8.0	10.7	0.0	4.6	14.5	40.5	0.0	0.0	0.0	0.0
CAP-FI-FC	40.0	23.0	26.2	0.0	0.0	0.0	0.0	0.0	8.4	1.2	1.1
CAP-FI-HV	25.6	11.9	7.3	0.0	7.7	5.7	41.8	0.0	0.0	0.0	0.0
SML-DI-FC	55.3	16.2	28.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SML-FI-FC	46.1	21.8	32.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	37.7	16.5	18.5	9.8	0.8	1.3	3.2	4.4	2.7	1.9	3.2

Source: Elaborated by authors

Note: AVG-DI-FC=Average producer, diversified income, producing field crops; AVG-FI-FCI=Average producer, farm income, producing field crops; AVG-DI-HV=Average producer, diversified income, producing high-value crops; CAP-FI-FC=Capitalized producer, farm income, producing field crops; CAP-FI-HV=Capitalized producer, farm income, producing high-value crops; SML-DI-FC=Small producer, diversified income, producing field crops; SML-FI-FC=Small producer, farm income, producing field crops.

There are differences in the output mix of different farm household types with associated regional differences (Table 5.6). Major crops for all types are clover, wheat, maize and, in Lower Egypt, rice. Between 80 and 100 percent of total revenue of households producing high-value crops comes from these four crops. This is in accordance with previous studies (Ouda and Zohry 2015). The remaining share results from the production of sugar beet, cotton, and, in Upper Egypt, sugarcane. Households producing high-value crops get almost 60 percent of their revenue from fruits and vegetables, garlic, onion, potato, and tomato. There are some regional differences in terms of crop mixes. For example, rice production is only allowed in Lower Egypt, so farmers in Upper Egypt rely on maize as a summer crop. Production of garlic, onion, potato, and tomato contribute the most to total revenue among high-value crop producers in Upper Egypt at 40 percent, while the share in total revenue of these crops in Lower Egypt is close to 20 percent only.

Table 5.7. Share of different crops in total area harvested, percent, by region and farm household type

Type	Wheat	Clover	Maize	Rice	Fruits	Vege-tables	Garlic, onion, potato, tomato	Sugar beet	Sugar cane	Cotton	Other
Lower Egypt	31.1	22.6	7.9	26.9	0.5	0.6	0.5	6.3	2.5	0.0	1.2
AVG-DI-FC	33.5	21.8	10.7	24.4	0.0	0.0	0.0	9.1	0.5	0.0	0.0
AVG-FI-FC	29.6	22.3	5.8	28.9	0.0	0.0	0.0	5.7	3.6	0.0	4.1
AVG-DI-HV	31.2	17.3	4.5	14.7	7.4	14.4	10.5	0.0	0.0	0.0	0.0
CAP-FI-FC	20.4	27.6	2.9	36.9	0.0	0.0	0.0	5.4	6.7	0.0	0.0
CAP-FI-HV	44.7	17.6	6.2	7.4	15.3	2.1	6.7	0.0	0.0	0.0	0.0
SML-DI-FC	52.0	18.0	18.5	11.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SML-FI-FC	35.8	22.4	6.7	35.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Upper Egypt	38.9	30.5	20.9	0.0	0.4	1.1	2.3	0.9	0.6	1.4	3.0
AVG-DI-FC	38.1	32.3	20.2	0.0	0.0	0.0	0.0	3.2	2.5	0.2	3.5
AVG-FI-FCI	39.1	31.3	22.1	0.0	0.0	0.0	0.0	0.0	0.0	2.8	4.6
AVG-DI-HV	32.2	21.8	16.4	0.0	3.1	8.7	17.8	0.0	0.0	0.0	0.0
CAP-FI-FC	37.9	23.8	34.5	0.0	0.0	0.0	0.0	2.1	0.0	1.3	0.5
CAP-FI-HV	33.1	28.3	16.3	0.0	2.4	5.8	14.2	0.0	0.0	0.0	0.0
SML-DI-FC	46.7	40.4	13.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SML-FI-FC	48.7	31.3	19.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	34.6	26.1	13.7	14.9	0.5	0.8	1.3	3.9	1.6	0.6	2.0

Source: Elaborated by authors.

Note: AVG-DI-FC=Average producer, diversified income, producing field crops; AVG-FI-FCI=Average producer, farm income, producing field crops; AVG-DI-HV=Average producer, diversified income, producing high-value crops; CAP-FI-FC=Capitalized producer, farm income, producing field crops; CAP-FI-HV=Capitalized producer, farm income, producing high-value crops; SML-DI-FC=Small producer, diversified income, producing field crops; SML-FI-FC=Small producer, farm income, producing field crops.

Land allocation to different crops by household types is shown in Table 5.7. The crop using the most land is clover, followed by wheat, which is the major crop measured in terms of value of production. Maize and rice show similar share in total area, with maize being the major summer crop in Upper Egypt, while rice is the most profitable summer crop in Lower Egypt. Area allocated to vegetables, garlic, onion, potato, and tomato is 2.3 percent of the total area harvested in Upper Egypt, while Lower Egypt only harvests these crops on 0.5 percent of the total area. Note that the capitalized household producing high-value crops in Lower Egypt, rely mostly in the production of fruits (15 percent of the area), while in Upper Egypt, capitalized high-value producers allocate only 2.4 percent of their area to fruits and almost 20 percent to vegetables, garlic, onion, potato, and tomato.

Table 5.8. Contribution of household types to total revenue of different crops, by region and farm household type

Type	Wheat	Clover	Maize	Rice	Fruits	Vege- tables	Garlic, onion, potato, tomato	Sugar beet	Sugar cane	Cotton	Other
Lower Egypt	50.9	53.6	100.0	27.6	59.4	30.9	17.2	94.5	0.0	93.1	50.9
AVG-DI-FC	14.0	11.2	18.8	11.4	0.0	0.0	0.0	2.9	0.0	32.2	14.0
AVG-FI-FC	18.5	17.1	33.0	9.1	0.0	0.0	0.0	30.9	0.0	30.4	18.5
AVG-DI-HV	1.7	1.2	1.5	0.6	23.5	28.0	11.7	0.0	0.0	0.0	1.7
CAP-FI-FC	13.5	22.4	44.7	4.8	0.0	0.0	0.0	60.7	0.0	30.5	13.5
CAP-FI-HV	1.8	0.9	0.6	0.6	35.9	3.0	5.5	0.0	0.0	0.0	1.8
SML-DI-FC	0.8	0.3	0.3	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.8
SML-FI-FC	0.6	0.5	1.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.6
Upper Egypt	49.1	46.4	0.0	72.4	40.6	69.1	82.8	5.5	100.0	6.9	49.1
AVG-DI-FC	6.0	6.3	0.0	8.1	0.0	0.0	0.0	5.5	1.3	4.3	6.0
AVG-FI-FCI	28.2	27.7	0.0	40.3	0.0	0.0	0.0	0.0	90.0	0.0	28.2
AVG-DI-HV	6.3	5.2	0.0	8.1	34.2	59.6	69.7	0.0	0.0	0.0	6.3
CAP-FI-FC	5.5	4.2	0.0	12.6	0.0	0.0	0.0	0.0	8.7	2.5	5.5
CAP-FI-HV	1.5	1.6	0.0	1.9	6.4	9.5	13.1	0.0	0.0	0.0	1.5
SML-DI-FC	0.5	0.5	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.5
SML-FI-FC	1.0	0.8	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: Elaborated by authors.
Note: AVG-DI-FC=Average producer, diversified income, producing field crops; AVG-FI-FCI=Average producer, farm income, producing field crops; AVG-DI-HV=Average producer, diversified income, producing high-value crops; CAP-FI-FC=Capitalized producer, farm income, producing field crops; CAP-FI-HV=Capitalized producer, farm income, producing high-value crops; SML-DI-FC=Small producer, diversified income, producing field crops; SML-FI-FC=Small producer, farm income, producing field crops.

Table 5.8 shows the distribution of land area allocated to each crop across household types. Only the area of wheat and clover are distributed in the same proportion between Lower and Upper Egypt. Other crops show very different patterns, which reflects the importance of environmental factors in determining production systems in Egypt and highlights the need for disaggregating household types by region. As mentioned, rice is produced only in Lower Egypt, which makes maize the major summer crop in Upper Egypt, where is found 72 percent of the total maize area in Egypt. Sixty percent of the area under fruit trees is in Lower Egypt, but 70 percent of the area of vegetables and 83 percent of the area of garlic, onion, potato, and tomato are in Upper Egypt. In our sample, sugar beet and cotton are almost exclusively planted in Lower Egypt, while the opposite is true in the case of sugarcane.

Which household types play a bigger role in the production of the different crops? About 75 percent of the area under clover and 78 percent of the area under wheat is harvested by average producers growing field crops in Lower Egypt and the average producer specialized in field crops in Upper Egypt. Almost 45 percent of rice area is harvested by capitalized farmers, the rest being under average field crop producers in Lower Egypt. In contrast, only 13 percent of the maize area in Upper Egypt is planted by capitalized households. Finally, notice that most of the area of high-value crops is under average households both in Lower and Upper Egypt. Capitalized farmers only have a significant share of the area of fruits (35 percent), and they are in Lower Egypt.

6. HOUSEHOLD TYPES AND CLIMATE CHANGE

In addition to the limitations facing the agriculture sector, studies suggest that climate change will likely have a strong and mostly negative impact on Egypt in terms of agricultural production, availability of water resources, food security, and ultimately farmer livelihoods (Smith et al. 2013; Eid et al. 2007; McCarl et al. 2015). Thus identifying, applying, and upscaling suitable adaptation measures, particularly at the farm level, is critical.

The major potential impacts resulting from climate change are, according to Smith et al. (2013): changes in water supplies, reduction in crop yields and in agricultural production, and coastal inundation and loss of productive land. With changes in water supply, the potential reduction in Nile water flows may severely affect Egypt and the population living in the Nile Valley and Delta (Smith et al. 2013). Higher evaporation rates due to increases in temperature, not only in Egypt but also in other upstream Nile Basin countries, most importantly Ethiopia, will exacerbate water stress and affect Egypt's agriculture sector (McCarl et al. 2015; Smith et al. 2013).

A study conducted by UNDP on the potential impacts of climate change in Egypt uses a range of Global Circulation Models (GCMs) to estimate future temperature, precipitation, and Nile water flows. According to the study, temperature is expected to increase by an average of 1 degree Celsius by 2030, and 2 degrees by 2060, while annual precipitation is expected to decrease according to most scenarios, between 4 and 10 percent (Smith et al. 2013). With an increase in temperature, the water demand of major crops is expected to increase between 6 and 8 percent. It is estimated that if the Nile water flows decrease by 12 percent, agricultural production could drop by more than 25 percent (Smith et al. 2013).

Because of such climate change conditions, yields of major crops in Egypt, including wheat, rice, and maize, are predicted to decrease significantly, while crop water requirements are expected to increase (Smith et al. 2013). A study assessing the economic impacts of climate change on agriculture in Egypt found that net farm revenues would be negatively affected with increases in temperature. Net revenues would be reduced by almost $1,000 per hectare in case of a 1-degree Celsius rise in temperature (Eid et al. 2007). Crop yields are expected to decline according to all scenarios by 2060. Vegetables are predicted to experience the highest yield reduction, especially tomatoes, for which yields could decrease by 28 percent. Major field crops, like wheat, sugarcane, maize, and rice, will experience an average yield decrease of between 15 and 19 percent (Smith et al. 2013). On the other hand, onion seems to be a strong standing crop, as yield decreases by 2060 are estimated at less than 2 percent.

As for sea level rise, the optimistic scenario in the study by Smith et al (2013) predicts a 20-cm rise in sea level by 2060, while a more pessimistic scenario predicts a 50-cm rise. Some locations in the Delta, most notably Port Said, followed by Al Burullus and Alexandria, will have a higher relative rise in sea level due to the higher rate of inundation in these areas. Thus, smallholder farmers in these two governorates are particularly vulnerable to climate change risks and loss of crops. If the Delta's agricultural lands are not protected from sea level rise, one-fifth of the agricultural land in the Northeast Delta is at risk of inundation (Smith et al. 2013). Other studies estimate that the Delta's low-lying areas and the coast most vulnerable to sea level rise make up between 30 and 40 percent of the country's agricultural production (McCarl et al. 2015; Darwish et al. 2013).

We analyze the potential impact of increased temperature and reduction of water flows on agricultural production and revenues by farm household type in Egypt, assessing the changes in land allocation that could improve their income and safeguard their livelihoods under new climate conditions.

Climate change scenarios

Following Smith et al. (2013), we consider changes in three main factors affecting agricultural production by the year 2050: (i) changes in water demand by crops; (ii) changes in yields; and (iii) changes in water flow in the Nile. The first two factors are the result of increased temperatures. According to Smith et al. (2013), Egypt is getting warmer. From 1961 to 2000, the mean maximum air temperature increased 0.34^o Celsius per decade, while the mean minimum air temperature increased 0.31^oC per decade. From 1971 to 2000, a clear warming trend was observed in all weather stations across the country. Additionally, the Intergovernmental Panel on Climate Change (IPCC) concluded that Egypt will probably get hotter and drier. Projected changes in temperature are from Smith et al. (2013) who obtained them from comparisons of different climate change models. These models project almost the same amount of increase in temperature for Cairo: a 1°C change by 2030 and about 2°C by 2060. For our analysis, we interpolate these results to obtain an increased temperature of 1.6°C by 2050. For simplicity, we assume that this increase applies to all regions in Egypt.

Water demand for crop production

We calculate changes in water demand by crop following FAO's guidelines for crop-water requirements (*ETc*), through the product of the reference-crop evapotranspiration (*ETo*) and the crop coefficient (*Kc*):

$$ETc = Kc \times ETo$$

The effect of climate on crop water requirements is given by *ETo*[6], a direct function of temperature. Equations to calculate it are described in Doorenbos and Pruitt (1977) and revised by Allen et al. (1998). The effect of the crop characteristics on crop water requirements is given by the crop coefficient (*Kc*) which presents the relationship between reference (*ETo*) and crop evapotranspiration. Values of *Kc* vary with the crop, its stage of growth, growing season, and prevailing weather conditions. Table 6.1 presents the calculated increases in water demand by crop for Lower and Upper Egypt.

Table 6.1. Increase in water demand by crop as a result of an average increase of 1.6^oC in temperature, percent

Crop	Lower Egypt	Upper Egypt	Crop	Lower Egypt	Upper Egypt
Clover	3.4	3.5	Rice	4.1	-
Cotton	3.8	3.9	Sorghum	4.1	4.3
Dry beans	3.9	4.1	Sugar beet	4.1	4.2
Fruit	3.8	4.0	Sugarcane	-	4.0
Garlic	3.8	4.0	Tomato summer	4.1	4.3
Maize	4.1	4.3	Tomato winter	3.8	4.0
Onion	3.8	4.0	Vegetables summer	4.2	4.3
Peanut	4.1	4.3	Vegetables winter	3.9	4.1
Potato	3.8	4.0	Wheat	3.5	3.7

Source: Calculated by authors

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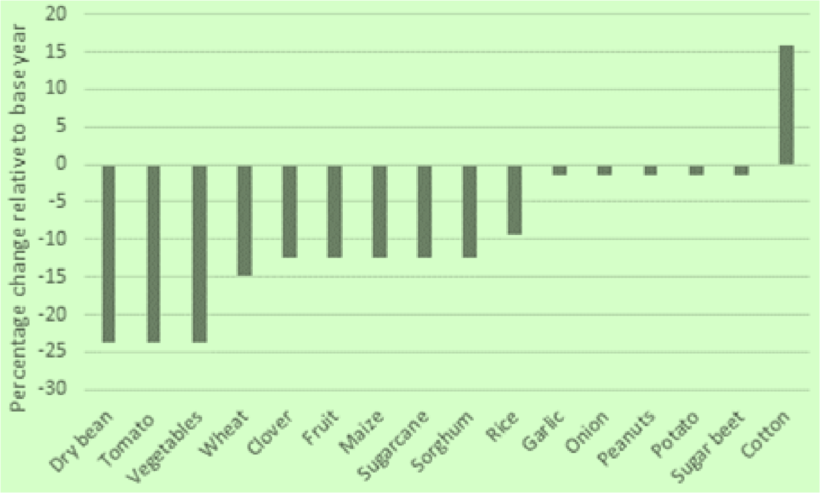
[6] ETo is defined as "the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water" (Doorenbos and Pruitt 1977).

Crop yields

Crop yield projections to 2050 are from Smith et al. (2013) who rely mostly on the Egypt Second National Communication (EEAA 2010) modified through interpolations to the years 2030 and 2060. Smith et al. (2013) also used these data to assign yields to crops for which there was no information available. Change in global supply and demand for certain crops could also affect production in Egypt. On average, warmer temperatures will decrease relative yields of grain crops, such as wheat, in lower latitudes, putting Egypt at a disadvantage, decreasing exports, and increasing imports. Original estimation of yield changes in EEAA (2010) were limited to wheat (-15 percent), rice (-11 percent), maize (-14 to -19 percent), soybean (-28 percent), barley (-20 percent), cotton (17 percent) and potato (-0.9 to -2.3 percent). Smith et al. (2013) took these values and adjusted them "to be consistent with the climate change scenarios through expert judgment" and used them to "estimate change in agricultural output for a variety of crops that were not individually modeled." The expert judgment and extrapolation introduce additional uncertainty into the results. Yield changes from Smith et al. (2013) adjusted to reflect changes by 2050 for the group of crops in our sample are shown in Figure 6.1.

Figure 6.1. Projected changes in crop yields to 2050, selected crops



Source: Adapted from Smith et al. (2013)

A major limitation of these yield projections according to Smith et al. (2013) is that the original sources do not specify the underlying climate change scenario. Consequently, results obtained from these projections should be taken with caution.

In sum, yields decreases are expected for all crops except cotton, due to higher temperatures. Particularly susceptible to higher temperatures are pulses, vegetables, and tomato, followed by wheat. Yields of onion, potato, garlic, peanuts, and sugar beet are the less susceptible to higher temperatures, while cotton yields are expected to be positively affected by increased temperatures.

Nile water flows

We assume that for the case of Egypt, changes in precipitation due to climate change are not important since 95 percent of agriculture in Egypt is irrigated and depends on water from the river Nile. What matters most for Egypt is the level of flow in the Nile, which depends on precipitation in the upstream watershed of the Nile in East Africa and in Ethiopia, more than 1,000 kilometers from Egypt's southern border. Three-fifths of the Nile's flow is from the Blue Nile, which originates in the Ethiopian Highlands; while the remaining two-fifths are contributed by the White Nile with its sources in the Equatorial Lakes region of East Africa. According to Smith et al. (2013), there is disagreement about whether East Africa will get wetter under climate change, but cite studies showing that precipitation during the growing season (March, April, and May) in East Africa has decreased by approximately 15 percent since 1980 and that warmer surface temperatures in the Indian Ocean increasingly are disrupting the flow of moisture from the ocean to this region. In contrast, the IPCC asserts that East Africa is likely to get wetter under climate change – roughly two-thirds of the general circulation models (GCMs) project an increase in precipitation in East Africa (Smith et al. 2013). What is relevant for this study are the consequences of different Nile flow scenarios for different types of producers.

Smith et al. (2013) refer to 17 GCMs simulating changes in the Nile flow that go from large decreased flows to increased flows. The wettest model projects a flow increase of one-fourth in 2060 compared to present values. On the other hand, the driest model projects a reduction in water flows to the Aswan High Dam of 33 percent. The model close to the average of all the models discussed in Smith et al. (2013) projects a decrease of Nile flows of about 10 percent by 2060. This 10 percent reduction in flows to the Aswan High Dam is what we use to look at the impact of water constraints on farm types. The equivalent numbers for changes in Nile flows by 2050 are a 22 percent increase for the increased precipitation scenario; a 9 percent decrease for the average scenario; and a 30 percent decrease for the driest scenario.

Other factors

Even though our focus is on the impact of climate change, there are also substantial uncertainties about future socioeconomic conditions in Egypt due to population growth, economic development, changing demand, and technology. The overall impact of climate change will depend on the particular socioeconomic path followed by the country in coming decades. For example, water constraints and less favorable conditions for agriculture could result in slow agricultural growth or even reductions in food supply. This together with growing population and income could result in significant increases in food prices. But the magnitude of these increases will depend on government policies and openness to food imports. In this study, we only look at individual producer types assuming prices as exogenous. In our simulations, we use 2014 prices to look at the effect of changes in water demand and supply on production and income. It is important to keep in mind, however, that higher prices will offset in part the negative effect of climate change on farmer’s income.

According to results in Smith et al. (2013), if exports and imports of agricultural goods are no greater than five times the levels of 2007, food prices will increase when production decreases. Assuming pessimistic population (high growth) and economic growth scenarios, a low reduction in Nile flow with a decrease of just over 10 percent by 2060, and no protection from sea level rise, Smith et al. (2013) project that by 2030 agriculture production will decrease by 11 percent and prices will rise 26 percent. Under this scenario, the amount of land dedicated to agriculture will be reduced by 3.6 percent and there are 3.9 percent fewer labor hours engaged in agriculture. With almost nine million people employed in agriculture in Egypt in 2007, this means that more than 350,000 jobs could be at risk.

By 2060 under the same socioeconomic and climate change scenarios, conditions would be significantly worse according to Smith et al. (2013). Production drops 27 percent and imports of agricultural goods rise by 49 percent, prices increase by 41 percent, which leads to a reduction in consumption of agricultural goods by 15 percent, agricultural production is down 10 percent, and the level of employment is reduced by 20 percent, which at current employment rates would result in the loss of 1.8 million jobs. In our adaptation analysis (Chapter 7), we assumed that import restrictions are 10 times above 2007 levels, which will reduce the price increase by about one-half.

Summary of scenarios

Table 6.2 summarizes three climate change scenarios and a fourth adaptation scenario used in this study. The assumption behind the scenarios, following results from climate change models in Smith et al. (2013), is that a) the effect of climate change in Egypt will result in increased temperatures (1.6^{o}C in 2050); b) higher temperatures will result in increased water demand by crop, which in the case of Egypt means increased water use for irrigation; and c) higher temperatures will have a negative effect on crop yields, except for cotton, although this effect will vary by crop. A major effect on Egypt's agriculture could result from changes in Nile river flows into the Aswan High Dam, which are determined by precipitation in the sources of the Nile in sub-Saharan Africa, mainly Ethiopia and Uganda.

Results from climate change models present a range of situations from reduced precipitation and drier conditions in East Africa, resulting in lower Nile flows, to increased precipitation and wetter climate, leading to increased Nile flows. Given this uncertainty, we define three scenarios. All scenarios assume increased temperature, water demand, and negative impact on yields, but they differ in the assumptions about changes in water flows.

Table 6.2. Climate change scenarios that result from an increase of 1.6^{o}C in temperature by 2050

Scenarios	Description
Scenario 1	• Increased water demand by crops (Table 6.1), plus • Changes in crop yields (Figure 6.1), plus • Increase in Nile water flow by 22 percent, plus • Agricultural prices increase by 16 percent due to slow or negative agricultural growth and restrictive policies allowing food imports to only increase by five times relative to base year.
Scenario 2	• Scenario 1, plus • Change in crop yields due to an increase of 1.6°C in temperature by 2050, plus • Reduction in Nile water flow by 9 percent, plus • Same import restrictions as in Scenario 1, resulting in food prices increasing by 41 percent
Scenario 3	• Scenario 1, plus • 30 percent reduction in water available for irrigation by 2050, plus • Reduction in Nile water flow by 30 percent, plus • Same import restrictions as in Scenario 1, resulting in food prices increasing by 68 percent
Scenario 4	Adaptation scenario: • Same as Scenario 3, plus • All household types have more flexibility to allocate resources to crops, plus • Can allocate family labor to non-farm activities to earn wages, plus • Can rent land to expand area, plus • Face less restrictive policies than in previous scenarios, food imports increase by a factor of ten and agricultural prices increase by 34 percent

Source: Elaborated by authors

To look at possible responses to climate change, we implement also an adaptation scenario which uses the most pessimistic climate changes, Scenario 3, but introduces the following changes:

a) We eliminate constraints on land use by running a linear programming problem that allows household types to depart from initial land use by having more flexibility to allocate resources among crops and to specialize in smaller number of activities;

b) Households can allocate farm family labor to off-farm activities, receiving average regional wages defined by the mix of agriculture and non-agriculture employment available, weighted by the share of non-farm income in total income. The assumption here is that households with a high proportion of non-farm income at present have better links to labor markets than households with low share of non-farm income. These households with considerable non-farm income are more likely to allocate labor to other activities than households with poor links to non-farm labor markets.

c) We also allow households to rent land to expand their area if it would be profitable, paying rent for the new land.

d) Finally, for the adaptation scenario, we assume that the government implements a less restrictive agricultural policy allowing food imports to increase ten times above 2007 levels, instead of five times as in scenarios 1 to 3. This reduces price increase by about one-half with respect to Scenario 3, according to Smith et al. (2013).

The impact of these projected conditions on income and resource allocation of the various farm household types are discussed in the next section.

Simulations

We use Positive Mathematical Programming (PMP, Howitt 1995) to simulate the impact of changes in temperature, water availability, and changes in yields on household outcomes. The household maximizes a nonlinear objective function subject to constraints given by household endowments of land, labor, capital, and water for irrigation:

$$\max_x \Pi = \sum_m p_m y_m x_m - \left(\sum_m d_m x_m + 0.5 \sum_m q_m x_m^2 \right)$$

Subject to:

$$\begin{aligned} &\textstyle\sum_m a_{m,j} x_m \leq B_j \ \ [\lambda_j], \qquad\qquad (6.1) \\ &x_m \geq 0 \text{ and } j=[\mathit{land, labor, capital, water}] \end{aligned}$$

where x_m represents the level of activity/crop *m* in feddans, y_m are yields of crop *m*, p_m is price of crop *m*, *d* and *q* are parameters of a quadratic cost function, $a_{m,j}$ are technical coefficients, such as, for example, the amount of resource *j* per feddan used by crop *m.* There are several methods to calibrate the household model to its base year values. For computational simplicity for this exercise, we define *d* as the variable cost per feddan of each crop, including inputs like fertilizer and services. We set all off-diagonal elements of the quadratic cost function equal to zero (as in Arfini and Paris 1995), so the q_m coefficients in (6.1) are the diagonal elements of a matrix Q defined as follows:

$$q_m = \frac{\rho_m}{x_m^o} \qquad (6.2)$$

where x^o_m is the level of activity *m* in the base year and ρ_m is the shadow price derived from the following linear programming (LP) problem:

$$\max_x \Pi_{LP} = \sum_m p_m y_m x_m - \sum_m d_m x_m$$

Subject to:

$$\begin{aligned} &\textstyle\sum_m a_{m,j} x_m \leq B_j \ \ [\lambda_j], \qquad\qquad (6.3) \\ &x_m \leq x_m^o + \varepsilon \ \ [\rho_m], \\ &x_m \geq 0 \text{ and } j=[\mathit{land, labor, capital, water}] \end{aligned}$$

The last equation in (6.3) is a calibration constraint forcing the optimal solution of the LP model to reproduce the observed base year activity levels x^o, within the range of the positive perturbations of the calibration constraints, ε.[7] The dual values of the calibration constraints (ρ) are

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[7] ε is a small positive value

employed to specify the non-linear cost function such that the marginal cost of activities is equal to their respective prices at the base year activity levels x^o (Heckelei and Britz 2005). Howitt (1995) and Paris and Howitt (1998) interpret the dual variable vector ρ associated with the calibration constraints as capturing any type of model miss-specification, data errors, aggregation bias, risk behavior, and price expectations. In other words, unobserved factors defining the observed land allocation and activity levels are incorporated into the cost function in problem (6.1) through the dual variables of the calibration constraints in problem (6.3). The solution to problem (6.1) calibrated in this way reproduces the exact land and input use of the base year without the need of using the calibration constraints as in (6.3). Problem (6.1) is then used to run simulations by changing some of the values of the *A* coefficients (water demand by crop), water availability (included in the vector of endowments *B*), and yield levels (*y*).

For the adaptation scenario (Scenario 4), we run the following LP problem:

$$\max_{x,FL,R} HHI = \Pi_{LP} + wFL - rR$$

Subject to:

$$\sum_m a_{m,i} x_m \le B_i \quad [\lambda_i] \quad \text{for i=[capital, water for irrigation]}$$

$$\sum_m x_m \le B_{land} + R_{land} \quad [\lambda_{land}] \qquad (6.4)$$

$$\sum_m a_{m,labor} x_m \le B_{family\ labor} - FL \quad [\lambda_{labor}]$$

where *HHI* is total household income, Π_{LP} is profit from agricultural production as in (6.3), *FL* is family labor allocated to off-farm activities, *w* is wage earned in off-farm activities, and *R* is land in feddan rented at price *r*.

7. SIMULATION RESULTS AND POLICY OPTIONS

Climate Change Scenarios

We look at the effect of the climate change scenarios on output, land and labor use, and income of different household types. Table 7.1 shows that the projected increase in temperature combined with water constraints by 2050 will have a significant negative effect if they result in reduced Nile water flows (Scenarios 2 and 3). Scenario 1 shows that, if precipitation in East Africa increases as a result of climate change, increased water availability will compensate for reduction in yields and increased water demand, resulting in small changes in output, labor use, and harvested area. The aggregated result for all household types shows an increase of 15 percent in total output, 6 percent increase in agricultural family labor, and 4 percent increase in harvested area.

The effect of a small reduction in water flows (Scenario 2) could reduce output of households in Upper Egypt to 83 percent and reduce the demand for labor and harvested area to 92 percent of their levels in 2014. The effect of a small reduction in water flows is smaller for households in Lower Egypt with only a 7 percent reduction in output.

Table 7.1. Output, land, and labor use in 2050 by household types under different climate change scenarios relative to levels in the base year, 2014=100

	Output			Labor used			Area harvested		
Type	**Sc 1**	**Sc 2**	**Sc 3**	**Sc 1**	**Sc 2**	**Sc 3**	**Sc1**	**Sc2**	**Sc 3**
AVG-DI-FC	117	87	77	99	101	92	100	89	71
AVG-FI-FC	116	86	76	101	96	84	100	89	70
AVG-DI-HV	114	108	93	95	116	89	99	106	84
CAP-FI-FC	150	115	107	157	146	126	138	121	94
CAP-FI-HV	117	126	130	105	136	140	102	131	113
SML-DI-FC	107	84	77	99	102	101	100	90	72
SML-FI-FC	110	81	68	99	93	79	100	89	70
Lower Egypt	**121**	**93**	**83**	**110**	**108**	**96**	**107**	**96**	**76**
AVG-DI-FC	108	81	64	99	96	75	100	90	70
AVG-FI-FCI	107	83	64	99	86	67	100	93	71
AVG-DI-HV	106	89	72	112	118	96	101	98	77
CAP-FI-FC	107	81	65	99	96	77	100	88	67
CAP-FI-HV	103	87	74	106	114	101	99	89	70
SML-DI-FC	106	77	61	99	82	56	100	88	68
SML-FI-FC	101	78	63	99	80	51	100	88	67
Upper Egypt	**107**	**83**	**65**	**101**	**92**	**72**	**100**	**92**	**71**
All	**115**	**88**	**75**	**106**	**101**	**85**	**104**	**94**	**74**

Source: Elaborated by authors.
Note: Sc1 (Scenario 1) = Increased water demand by crops + Changes in crop yields + Increase in Nile water flow + 16% increase food prices; Sc2 = Sc1 + Small reduction in Nile water flow of 9% + 41% increase in food prices; Sc3 = Sc1 + Large reduction in Nile water flow + 68% increase in food prices.

On the other hand, a large reduction of Nile water flows could have major effects not only on output, but also on the use of land and labor, particularly for households in Upper Egypt (Table 7.1, Scenario 3).[8] Total output of these households could drop by 35 percent, family labor in agriculture by 15 percent, and harvested area could drop to 71 percent of the harvested area of 2014. Households in Lower Egypt will be less affected, but output will still decrease by 17 percent and the area harvested by 24 percent. These two household types will also see an increase in family labor in agricultural production. Capitalized farmers producing high-value crops will also expand their area harvested.

Looking at individual household types in Table 7.1, we find that the most resilient producers are capitalized households in Lower Egypt. In the worst-case scenario, Scenario 3, these households actually increase output – by 7 and 30 percent in households producing field crops and high-value crops, respectively. Average producers (AVG-DI-FC, AVG-FI-FC, AVG-DI-HV) and small producers (SML-DI-FC, SML-FI-FC) would have significant negative impacts in Scenario 3, with the small, agricultural income dependent household producing field crops experiencing the largest negative impact with a32 percent reduction in output and a 30 percent reduction in area harvested.

Households in Upper Egypt will pay the largest price for climate change. All households, including capitalized households, will see output reductions of 25 to 30 percent. The best performers in this context are those households producing high-value crops (AVG-DI-HV and CAP-FI-HV). Nonetheless, output levels for these households would drop by 28 and 26 percent, respectively.

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[8] Notice that the reduced cultivated area is a result of assuming constant yields in our simulations. Allowing for yield reduction from water constraints would have less impact on area cultivated and in labor demand but would have a similar effect on total output and a negative effect on land, water and labor productivity.

Table 7.2 shows changes in agricultural income under the different climate change scenarios. From a producer's perspective, reduced yields and water flows have a negative impact on agricultural output and, in the context of a relatively restrictive import policy, a decrease in output results in higher food prices. Given increased demand for water and reduced yields, the impact on prices is larger, the larger the constraint on water for irrigation.

Table 7.2. Agricultural income in 2050 by household types under different climate change scenarios relative to levels in the base year, 2014=100

	Agricultural Income			Total Income		
Type	**Sc 1**	**Sc 2**	**Sc 3**	**Sc 1**	**Sc 2**	**Sc 3**
AVG-DI-FC	149	156	190	104	105	108
AVG-FI-FC	159	172	212	126	131	149
AVG-DI-HV	148	185	238	111	120	132
CAP-FI-FC	208	228	315	137	144	175
CAP-FI-HV	143	188	269	121	142	180
SML-DI-FC	129	147	178	102	103	104
SML-FI-FC	134	146	170	124	133	149
Lower Egypt	**161**	**174**	**220**	**117**	**121**	**134**
AVG-DI-FC	133	149	172	103	105	107
AVG-FI-FCI	132	154	181	117	129	143
AVG-DI-HV	130	168	202	111	126	139
CAP-FI-FC	138	158	188	125	139	159
CAP-FI-HV	129	162	200	121	144	171
SML-DI-FC	123	135	148	102	103	104
SML-FI-FC	117	135	148	110	121	128
Upper Egypt	**131**	**152**	**178**	**112**	**121**	**132**
All	**148**	**165**	**201**	**115**	**121**	**133**

Source: Elaborated by authors.
Note: Sc1 (Scenario 1) = Increased water demand by crops + Changes in crop yields + Increase in Nile water flow + 16% increase food prices; Sc2 = Sc1 + Small reduction in Nile water flow of 9% + 41% increase in food prices; Sc3 = Sc1 + Large reduction in Nile water flow + 68% increase in food prices.

Table 7.2 shows changes in agricultural income under the different climate change scenarios. From a producer's perspective, reduced yields and water flows have a negative impact on agricultural output and, in the context of a relatively restrictive import policy, a decrease in output results in higher food prices. Given increased demand for water and reduced yields, the impact on prices is larger the larger the constraint on water for irrigation. Results shown in Table 7.2 indicate that price increases compensate for output losses, and all household types are better off as a result of climate change.

In Scenario 3, the worst-case scenario, average agricultural income doubles and total income increases by 33 percent. As in the case of changes in output, household types in Lower Egypt benefit the most from projected changes, increasing agricultural income by 2.2 times and total income by 34 percent in Scenario 3. Capitalized households show the highest increases in income (315 and 269 relative to 100 in 2014), but all other types show significant increases in income. Households in Upper Egypt also see large increases in income under Scenario 3, the smallest increase being that of small producers (48 percent in agricultural income and 4 to 28 percent in total income).

Notice that price increases are assumed to be the result of still restrictive agricultural policies. Relaxing these policies to increase food imports will mitigate the price increase, which is a measure that future governments would take to benefit consumers, who would clearly be worse off as a result of climate change. Controlling price escalation will have negative effects on producers, reducing the compensation for output losses they obtained from higher prices.

Table 7.3 depicts the effect of the climate change scenarios on the area cultivated for different crops, on average, for Lower and Upper Egypt in 2050. In the case of Lower Egypt, households reduce the share of field crops with increasing water stress from 83 percent in the base year to 77 percent in Scenario 3, while increasing the share of onion and potato in total area. Rice and wheat are the field crops losing the most share among field crops due to water constraints, while the share of maize increases. Among high-value crops, the share of vegetables in harvested area remains relatively stable but drops by one percentage point in Scenario 3, with higher water constraints.

Table 7.3. Average land use by household types by crop under different climate change scenarios, percentage of total harvested area in 2050

	Lower Egypt				Upper Egypt			
	Base	**Sc1**	**Sc2**	**Sc3**	**Base**	**Sc1**	**Sc2**	**Sc3**
Clover	23.9	22.8	22.2	22.3	23.1	23.0	21.5	21.6
Wheat	14.4	18.7	14.8	11.0	17.7	17.2	17.5	17.2
Cotton	6.0	7.3	6.7	5.4	-	-	-	-
Maize	5.2	4.8	6.3	8.7	17.1	16.6	17.6	17.4
Rice	26.1	23.4	19.9	16.8	-	-	-	-
Sugarcane	-	-	-	-	3.5	3.5	6.1	8.0
Other field crops	7.9	8.1	9.7	12.5	5.4	6.2	3.9	2.9
Total Field Crops	**83.5**	**85.0**	**79.7**	**76.8**	**66.8**	**66.4**	**66.6**	**67.1**
Garlic	-	-	-	-	4.6	8.1	10.0	10.8
Onion	5.1	5.7	7.3	9.1	4.3	5.0	5.5	6.7
Potato	3.7	4.1	5.3	7.5	-	-	-	-
Vegetables	7.6	5.2	7.7	6.7	-	-	-	-
Other high-value crops	-	-	-	-	24.4	20.4	17.8	15.5
Total High-value Crops	**16.5**	**15.0**	**20.3**	**23.2**	**33.2**	**33.6**	**33.4**	**32.9**
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Source: Elaborated by authors.
Note: Sc1 (Scenario 1) = Increased water demand by crops + Changes in crop yields + Increase in Nile water flow + 16% increase food prices; Sc2 = Sc1 + Small reduction in Nile water flow of 9% + 41% increase in food prices; Sc3 = Sc1 + Large reduction in Nile water flow + 68% increase in food prices.

In the case of Upper Egypt, we do not observe changes in the share of field and high-value crops in total harvested area – these shares consistently remain at two-thirds and one-third for field crops and high-value crops, respectively, in all scenarios. No major changes occur in area share of field crops, with wheat and maize both being cropped on 17 percent of the harvested area in all scenarios. The major change observed in land use in Upper Egypt is the increase in the share of sugarcane and changes in the composition of high-value crops, where garlic and onion double their share from 8 to 16 percent of harvested area, displacing other high-value crops, suc as tomato and vegetables, which reduce their share from 24 percent in the base year to 15 percent in Scenario 3.

Tables 7.4 and 7.5 present changes in crop harvested area by household type under different climate change scenarios. In the case of Lower Egypt (Table 7.4), average and small producers of field crops facing increased water stress in almost all cases increase their cropped area of maize and sugar beet (Scenario 3) and reduce their cropped area of rice and wheat. Average producers of field and high-value crops (AVG-DI-HV) increase the cropped area of high-value crops (onion and vegetables) and reduce the area planted to field crops. Changes among capitalized producers of field crops (CAP-FI-FC) are like average households, planting increased area of sugar beet and maize, but they also increase area of cotton and clover, reducing the area of rice. Capitalized producers of field and high-value crops expand the cropped area of both groups of crops under increasing water constraints, with major increases in onion and potato. This is the only household type that increases the area of rice.

Table 7.4. Changes in harvested area of crops in Lower Egypt in 2050 by household types under different climate change scenarios relative to levels in the base year, 2014=100

	AVG-DI-FC			AVG-FI-FC			AVG-DI-HV			CAP-FI-FC			CAP-FI-HV			SML-DI-FC			SML-FI-FC		
	Sc1	Sc2	Sc3	Sc1	Sc2	Sc3	Sc1	Sc2	Sc3	Sc1	Sc2	Sc3	Sc1	Sc2	Sc3	Sc1	Sc2	Sc3	Sc1	Sc2	Sc3
Maize	97	122	144	96	121	144	102	111	97	95	123	148	102	135	130	99	117	133	100	124	147
Sugar beet	122	140	133	123	144	162	-	-	-	127	169	204	-	-	-	-	-	-	-	-	-
Wheat	98	104	86	98	79	49	98	118	68	-	-	-	99	126	126	98	103	104	98	83	58
Cotton	124	110	79	121	90	33	-	-	-	141	140	117	-	-	-	-	-	-	-	-	-
Clover	101	77	55	101	91	73	102	86	78	100	115	115	102	128	92	101	83	55	101	91	73
Rice	93	69	41	96	81	62	107	110	73	94	77	55	107	142	133	101	59	4	100	83	57
Peanut	-	-	-	116	147	177	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dry bean	-	-	-	82	71	51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Onion	-	-	-	-	-	-	118	144	151	-	-	-	118	148	175	-	-	-	-	-	-
Summer vegetables	-	-	-	-	-	-	72	106	128	-	-	-	72	118	130	-	-	-	-	-	-
Winter vegetables	-	-	-	-	-	-	72	97	5	-	-	-	72	118	90	-	-	-	-	-	-
Potato	-	-	-	-	-	-	-	-	-	-	-	-	116	144	171	-	-	-	-	-	-
Total	100	89	71	100	89	70	99	106	84	138	121	94	102	131	113	100	90	72	100	89	70

Source: Elaborated by authors.
Note: Sc1 (Scenario 1) = Increased water demand by crops + Changes in crop yields + Increase in Nile water flow + 16% increase food prices; Sc2 = Sc1 + Small reduction in Nile water flow of 9% + 41% increase in food prices; Sc3 = Sc1 + Large reduction in Nile water flow + 68% increase in food prices.

The impact of climate change is most significant in Upper Egypt. All household types reduce total harvested area by 30 percent under Scenario 3, higher than in Lower Egypt. In this context, households reduce the area of most crops, with only a few crops increasing their area in four of the seven types. The types that seem to cope better with climate change and increased water constraints are the average and capitalized households producing high-value crops. The average household type producing high-value crops (AVG-DI-HV) increases area of garlic, potato, summer tomato, summer vegetables, and onion, while the capitalized household producing high-value crops (CAP-FI-HV) increases area of garlic, onion, and tomato Both of these household types reduce the area of wheat, maize, and clover in all scenarios. Capitalized farmers producing field crops (CAP-FI-FC) do not reduce the area of wheat, maize, and clover as dramatically as other producers to cope with climate change. In addition, they increase the area of sugarcane with increased water constraints.

Table 7.5. Changes in harvested area of crops in Upper Egypt in 2050 by household types under different climate change scenarios relative to levels in the base year, 2014=100

	AVG-DI-FC			AVG-FI-FC			AVG-DI-HV			CAP-FI-FC		
	Sc1	Sc2	Sc3	Sc1	Sc2	Sc3	Sc1	Sc2	Sc3	Sc1	Sc2	Sc3
Maize	96	107	87	100	103	81	104	101	62	94	93	71
Sugar beet	118	118	101	-	-	-	-	-	-	-	-	-
Wheat	98	94	74	98	100	82	98	86	49	98	101	82
Cotton	126	18	0	-	-	-	-	-	-	202	19	0
Clover	101	84	65	102	98	73	101	90	78	101	78	55
Peanut	116	138	139	-	-	-	-	-	-	-	-	-
Dry bean	84	56	0	84	54	0	-	-	-	-	-	-
Onion	-	-	-	-	-	-	119	126	116	-	-	-
Summer vegetables	-	-	-	-	-	-	65	99	120	-	-	-
Winter vegetables	-	-	-	-	-	-	61	4	0	-	-	-
Garlic	-	-	-	-	-	-	182	211	169	-	-	-
Summer tomato	-	-	-	-	-	-	79	104	126	-	-	-
Winter tomato	-	-	-	-	-	-	78	68	30	-	-	-
Potato	-	-	-	-	-	-	118	137	150	-	-	-
Sorghum	95	100	67	100	103	66	-	-	-	87	81	32
Sugarcane	91	0	0	101	0	0	-	-	-	101	113	117
Total	100	90	70	100	93	71	101	98	77	100	88	67

	CAP-FI-HV			SML-DI-FC			SML-FI-FC		
	Sc1	Sc2	Sc3	Sc1	Sc2	Sc3	Sc1	Sc2	Sc3
Maize	102	93	76	100	87	67	100	87	67
Sugar beet	-	-	-	-	-	-	-	-	-
Wheat	98	93	43	98	78	47	98	72	33
Cotton	-	-	-	-	-	-	-	-	-
Clover	101	78	78	101	96	85	101	98	89
Peanut	-	-	-	-	-	-	-	-	-
Dry bean	-	-	-	-	-	-	-	-	-
Onion	120	138	138	-	-	-	-	-	-
Summer vegetables	59	51	27	-	-	-	-	-	-
Winter vegetables	56	0	0	-	-	-	-	-	-
Garlic	176	265	312	-	-	-	-	-	-
Summer tomato	83	106	128	-	-	-	-	-	-
Winter tomato	83	99	102	-	-	-	-	-	-
Potato	-	-	-	-	-	-	-	-	-
Sorghum	-	-	-	-	-	-	-	-	-
Sugarcane	-	-	-	-	-	-	-	-	-
Fruit	105	65	0	-	-	-	-	-	-
Total	99	89	70	100	88	68	100	88	67

Source: Elaborated by authors.
Note: Sc1 (Scenario 1) = Increased water demand by crops + Changes in crop yields + Increase in Nile water flow + 16% increase food prices; Sc2 = Sc1 + Small reduction in Nile water flow of 9% + 41% increase in food prices; Sc3 = Sc1 + Large reduction in Nile water flow + 68% increase in food prices.

In sum, reduction of Nile water flows and changes in crop yields as a result of climate change could have a significant negative effect on agricultural production in Egypt. Reduced water flows would reduce output, labor demand, and cultivated area. The effect of reduced water flows on output is relatively small on capitalized producers in Lower Egypt, while small and average household types producing field crops would suffer the highest negative impact from water constraints. These negative impacts, however, do not affect household incomes, as the loss in output is compensated for by projected increase in food prices that result from reduced production and a restrictive import policy. With reduced water flows, most household types reduce production of rice and wheat and increase the area of maize. These results suggest that agriculture in Egypt is likely to experience a significant reduction in output, labor demand, and cultivated area and increases in food prices as a result of climate change. Most affected by these changes will be consumers and small and average producers of field crops in Upper Egypt.

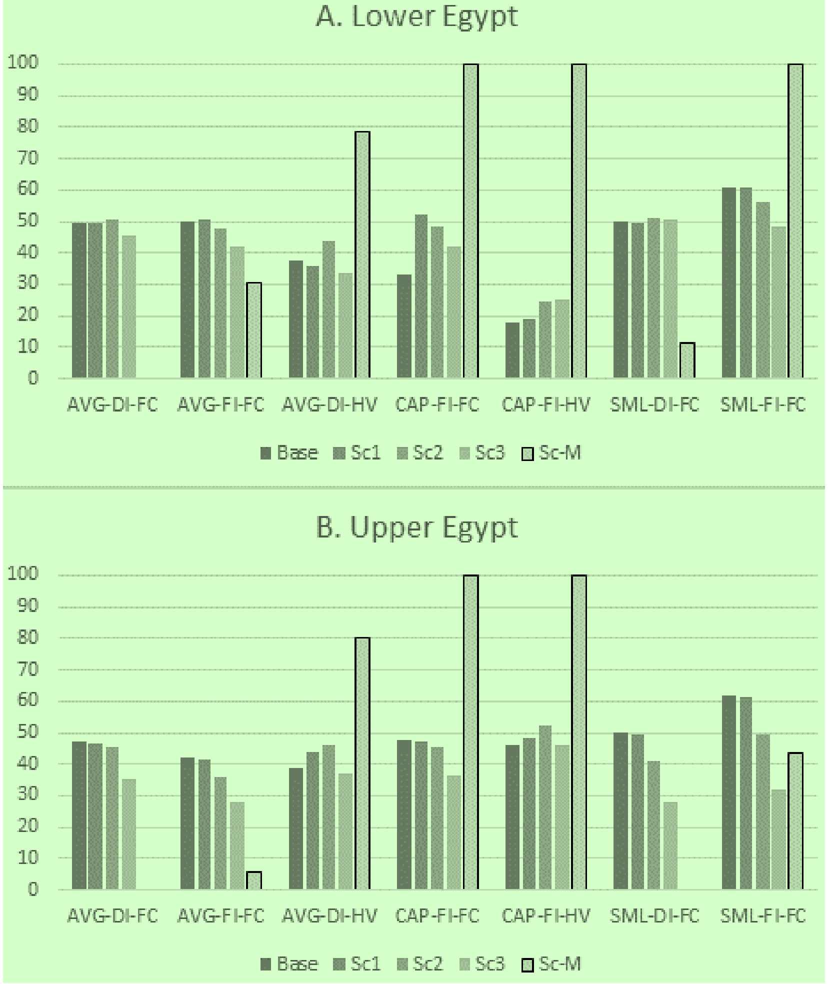
Mitigation Scenario

To examine coping mechanisms and policies that could minimize the negative impacts of climate change, we compare the climate change scenarios (Scenario 1 to 3) with a mitigation scenario (Scenario-M). This scenario is the same as Scenario 3 but with a major difference: in Scenario-M we drop the assumption that unobserved costs and constraints limit the possibilities that each type of farm household has to specialize in a reduced number of crops. For example, these unobserved constraints could result from the set of policies, incentives, and regulations behind the development of the agricultural sector in the past decades that incentivized production of wheat and other staples. Elimination of such policies and putting in place new policies to level the field between crops could result in higher flexibility for farm households to allocate resources. (See the definition of scenarios in section 5.) Unlike Scenario 3, we also allow family members to seek off-farm income and earn the opportunity cost of labor in their region – the average weighted income from non-farm self-employment or wages. Scenario-M also considers an agricultural sector that is more open to imports, which results in an increase in food price of 34 percent in 2050 instead of the 68 percent increase assumed in Scenario 3.

Figure 7.1 compares the allocation of family labor to agricultural production in different household types and in all scenarios, including the mitigation scenario (Sc-M). The figure shows that three household types in each region are capable of allocating more family labor to agricultural production, an indication of improved conditions for families to earn income in agricultural production. These types are the capitalized producers and the average producer with a production system of either field crops or high-value crops. Average types producing field crops find that seeking off-farm employment is a better option than agricultural production. For example, types AVG-DI-FC and SML-DI-FC in Upper Egypt allocate all their family labor to off-farm activities, while AVG-FI-FC allocates only 6 percent of total family labor available for agricultural production in the base year.

There is one exception among smallholders producing field crops: SML-FI-FC. This type with very small land area and scarce resources, but specialized in farm production, shows weak links to labor markets – the best option for them is to expand agricultural production. The situation for SML-FI-FC households seems to be very different between Lower and Upper Egypt. In Lower Egypt, this household type found activities that allow them to allocate all their labor force to production, increasing labor productivity well beyond its level in the base year (no climate change). This is not the case in Upper Egypt where SML-FI-FC households increase their allocation of family labor to agriculture, but only just above their level in the worst-case scenario. The possibilities of improving income through agricultural production for these households is very limited under all scenarios.

Figure 7.1. Allocation of family labor to agricultural production as a percentage of total available farm family labor for different household types under different climate change scenarios



Source: Elaborated by authors.
Note: Sc1 (Scenario 1) = Increased water demand by crops + Changes in crop yields + Increase in Nile water flow + 16% increase food prices; Sc2 = Sc1 + Small reduction in Nile water flow of 9% + 41% increase in food prices; Sc3 = Sc1 + Large reduction in Nile water flow + 68% increase in food prices. Sc-M = Same as Sc3 + Higher flexibility to allocate resources + Choice of allocating family labor to non-farm activities to earn wages + Rent land to expand area + Prices increase by 34%

What are the income implications of the mitigation scenario for the different types? This can be seen in Figure 7.2, which shows total income by household type for all scenarios. All households are better off in the mitigation scenario (Sc-M). The capitalized farmers in Lower Egypt increase their income by five and nine times with respect to the base year, and by four and five times in Upper Egypt. Similarly, average types producing high-value crops increased their income three to four times their level in the base year. Average household types that increased their share of off-farm activities in total income are also better off. In Lower Egypt, their income increased between 2.5 and 4.0 times their level in the base year. The equivalent figures for average types in Upper Egypt are 2.8 and 4.5 times their income in the base year. Finally, results for small producer types are less clear. For example, SML-DI-FC in Upper Egypt are clearly better off allocating family labor to off-farm activities. In Lower Egypt, these households are also better off in non-farm activities, but the difference with respect to the base year are smaller with only a 50 percent increase in income. The opposite is true for type SML-FI-FC. These households have better opportunities to increase income through agricultural production (2.5 times bigger than in base year) than do similar farmers in Upper Egypt (1.7 times bigger than in base year).

Figure 7.2. Total income under different climate change scenarios relative to levels in the base year, 2014=100

Source: Elaborated by authors.
Note: Sc1 (Scenario 1) = Increased water demand by crops + Changes in crop yields + Increase in Nile water flow + 16% increase food prices; Sc2 = Sc1 + Small reduction in Nile water flow of 9% + 41% increase in food prices; Sc3 = Sc1 + Large reduction in Nile water flow + 68% increase in food prices. Sc-M = Same as Sc3 + Higher flexibility to allocate resources + Choice of allocating family labor to non-farm activities to earn wages + Rent land to expand area + Prices increase by 34%

How did the successful agricultural producer types allocate their resources to increase their income in the mitigation scenario? Tables 7.6 and 7.7 shows land allocation in the base year and in the mitigation scenario for the farm household types in Lower and Upper Egypt, respectively. Changes in land allocation between the two scenarios show a very clear picture of the path to follow to mitigate the impacts of climate change. Capitalized and average producers of field and high-value crops need to rely more on high-value crops, like onion, potato, and tomato, and reduce the area of field crops. For example, in the case of the capitalized high-value producer type in Lower Egypt, onion, potato, and tomato represented 5 percent of harvested area in the base year, while in Sc-M the share increases to 60 percent. The same household type in Upper Egypt increases the share of onion, potato, and tomato in their farming from 12 to 44 percent of harvested area.

The only producers that can still specialize in field crops are capitalized producers. In Lower Egypt this is achieved by significantly reducing the area of rice and increasing clover-livestock and maize production. In Upper Egypt, capitalized field crop producers reduce the area of clover and cereals and increase sugarcane, a crop that uses water intensively but also produces high output value per feddan.

Table 7.6. Area harvested in Lower Egypt of different crops in the base year and in the mitigation scenario (Sc-M), for selected farm household types, feddans

	Clover	Maize	Rice	Wheat	Other field crops	Onion-potato-tomato	Other high-value crops	Total
Base year								
AVG-DI-HV	0.42	0.07	0.22	0.24	-	0.14	0.20	1.29
CAP-FI-FC	0.82	0.12	1.48	-	0.49	-	-	2.91
CAP-FI-HV	0.92	0.21	0.25	0.36	-	0.10	0.06	1.89
Scenario-M								
AVG-DI-HV	0.17	-	0.25	-	-	0.58	-	1.00
CAP-FI-FC	1.42	1.79	0.11	-	-	-	-	3.32
CAP-FI-HV	0.58	-	-	-	-	0.80	-	1.38

Source: Elaborated by authors.
Note: Sc-M = Same as Sc3 + Higher flexibility to allocate resources + Choice of allocating family labor to non-farm activities to earn wages + Rent land to expand area + Prices increase by 34%

Table 7.7. Area harvested in Upper Egypt of different crops in the base year and in the mitigation scenario (Sc-M), for selected farm household types, feddans

	Clover	Maize	Rice	Wheat	Other field crops	Onion-potato-tomato	Other high-value crops	Total
Base year								
AVG-DI-HV	0.53	0.35	0.36	-	-	0.20	0.27	1.70
CAP-FI-FC	1.47	1.47	0.92	-	0.11	-	-	3.97
CAP-FI-HV	1.32	0.73	1.13	-	-	0.50	0.44	4.13
Scenario-M								
AVG-DI-HV	0.13	-	-	-	-	0.65	-	0.78
CAP-FI-FC	0.20	-	0.51	0.48	-	-	-	1.18
CAP-FI-HV	0.52	-	1.22	-	-	1.38	-	3.12

Source: Elaborated by authors.
Note: Sc-M = Same as Sc3 + Higher flexibility to allocate resources + Choice of allocating family labor to non-farm activities to earn wages + Rent land to expand area + Prices increase by 34%

Policy options

Based on the findings on farm household characteristics and expected climate change impacts on those farm household types, this section provides strategic policy options. We go beyond the often-generalized recommendations and provide specific recommendations for each of the seven farm types in both Lower and Upper Egypt as summarized in Tables 7.8 and 7.9, respectively.

Table 7.8. Summary of findings and strategic policy options in the face of climate change for farm households in Lower Egypt, by type

Farm type	Impact of climate change	Strategies	Policies
Small producers	**Output and resource use**: Production could drop by 25 to 35 percent because of water constraints, reducing harvested area by 30 percent despite their very small land holdings. **Income**: With distortive policies and limited openness to trade in food, high prices would compensate for output losses, so overall income would remain stable or could even increase up to 50 percent	Very limited area and resources to increase income through agricultural production. Depend on government policies maintaining high food prices. Small producers will be better off increasing their off-farm income.	Policies that incentivize creation of non-agricultural jobs and improve skills of rural population to increase employment opportunities.
Average (smallholder) producer	**Output and resource use**: For producers of field crops, production could drop by 25 percent as a result of water constraints forcing reduction of harvested area by 30 percent reducing use of family labor by 8 to 16 percent. For producers of field and high-value crops, water constraints could reduce harvested area (30 percent) and use of family labor (11 percent) but output would only drop by 7 percent, which makes producers with diversified production systems more resilient. **Income**: With distortive policies and limited openness, high prices would compensate for output losses so: – overall income for field crop producers would remain stable or could even increase up to 50 percent. – overall income for field crop + high-value producers could increase by 30 percent.	Limited resources to increase income through production of field crops. Depend on government policies maintaining high food prices. With access to markets and knowledge, diversify into production of high-value crops. If not, average smallholder producers will be better off increasing their off-farm income.	Policies that incentivize creation of non-agricultural jobs and improve skills of rural population to increase employment opportunities. Develop value chains for water efficient high-value crops and access to markets for smallholders. Improve access to land, capital markets, and technology to promote capitalization of smallholder producers.
Capitalized producers	**Output and resource use**: Production could increase by 7 to 30 percent as a result of higher prices. Harvested area will remain stable or increase by 13 percent, while demand for family labor could increase by 26 to 40 percent. **Income**: With distortive policies, limited openness, and resultant high prices and a resilient production system, overall income of capitalized producers could increase by 80 percent.	Producers with diversified field crops + high-value crops can increase income even in the worst-case scenario of climate change by diversifying further into production of high-value crops. Best strategy for producers of field crops is to move away from rice production into clover-livestock-maize production.	Develop value chains for water efficient high-value crops, access to high income markets. Develop value chains of livestock products and feed industry.

Source: Elaborated by authors.

Table 7.9. Summary of findings and strategic policy options in the face of climate change for farm households in Upper Egypt, by type

Farm type	Impact of climate change	Strategies	Policies
Small producers	**Output and resource use**: Production could drop by 37 to 40 percent as a result of water constraints, reducing harvested area by 33 percent despite their very small landholdings, while use of family labor on farm could drop by 50 percent **Income**: With distortive policies and limited openness, high prices would compensate for output losses so overall income would remain stable or could even increase up to 28 percent	Very limited area and resources to increase income through agricultural production. Depend on government policies maintaining high food prices. Small producers will be better off increasing their off-farm income.	Policies that incentivize creation of non-agricultural jobs and improve skills of rural population to increase employment opportunities
Average (smallholder) producer	**Output and resource use**: For producers of field crops, production could drop by 35 percent as a result of water constraints forcing reduction of harvested area by 25 to 32 percent, reducing use of family labor by 28 to 30 percent. For producers of field and high-value crops, production could drop by 25 percent, harvested area decrease by 23 percent, and use of family labor by 4 percent. Producers with diversified production systems seem to be more resilient, but less resilient than the same type of producers in Lower Egypt **Income**: With distortive policies and limited openness, high prices would compensate for output losses, so: – overall income for field crop producers would remain stable or could even increase up to 43 percent. – overall income for field crop + high-value producers could increase by 40 percent.	Limited resources to increase income through production of field crops. Depend on government policies maintaining high food prices. With access to markets and knowledge, diversify to production of high-value crops. If not, better off increasing off-farm income.	Policies that incentivize creation of non-agricultural jobs and improve skills of rural population to increase employment opportunities Develop value chains for water efficient high-value crops and access to markets for smallholders. Improve access to land, capital markets, and technology to promote capitalization of smallholder producers
Capitalized producer	**Output and resource use**: Production could drop by 26 to 36 percent and harvested area could decrease by 30 percent, while demand for family labor could remain stable or decrease by 23 percent. **Income**: With distortive policies and limited openness, high prices would compensate for output losses and income of capitalized producers could increase by 60 to 70 percent.	All producers will be negatively affected. Producers of field crop + high-value crops can increase income by further diversifying into production of high-value crops. Best strategy for producers of field crops is to move away from cereal-clover production to crops with higher value per unit of land and water used.	Develop value chains for water efficient high-value crops and access to markets for smallholders. Develop value chains of livestock products and feed industry.

Elaborated by authors.

8. CONCLUSIONS

Using governorate-level national data and household survey data, we built a typology of farm households in Egypt that allows us to describe how different farm households behave in response to policy and environmental changes affecting their resources, welfare, and opportunities in output and input markets. To illustrate possible uses of the typology, we look at the vulnerability of different household types to projected changes in temperature, water availability, and water demand from crops due to climate change, and discuss which farmers, production systems, and regions will be most affected by climate shocks.

To build a comprehensive dataset of agricultural households, we combine different sources of data, drawing on governorate-level statistics from annual bulletins published by the Economic Sector of the Ministry of Agriculture and Land Reclamation (MoALR) and by the Central Agency for Public Mobilization and Statistics (CAPMAS). Household-level data was obtained from the 2012 round of the Egyptian Labor Market Panel Survey (ELMPS) conducted by the Economic Research Forum (OAMDI 2016). The full nationally representative sample includes information on employment, education, earnings and assets for 49,186 individuals in 12,060 households.

To model farm typologies, we applied a multi-step procedure that includes identifying variables (using a principal component analysis) for use in cluster analysis; standardizing selected variables and checking for outliers; investigating patterns of variation with different numbers of clusters and different variables; interpreting cluster results; reclassifying households; and constructing the typology. We identified seven household types based on the national sample, and then divided these seven types by Lower and Upper Egypt, for a total of 14 household types.

The first step was grouping households by relative availability of land, labor and capital in three major groups using cluster analysis: average producers, which are the most numerous and similar to the average household in the ELMPS survey; capitalized producers using high levels of capital and land per worker; and small producers, with low land and capital relative to total labor available. The second criterium used to group households was classifying households according to their sources of income (non-farm income and those depending on farm-income (more than 40 percent of total income). Finally, all groups were further divided depending on the importance of high-value crops in their production system into those producing field crops (cereals, oil crops and sugar crops) and those with at least 40 percent of their crop revenue coming from fruits, vegetables, tomato, onion, garlic and potato.

To illustrate possible uses of the typology in farm or sector-wide models, we look at the vulnerability of different types to projected changes in temperature, water availability, and water demand from crops due to climate change and discuss which farmers, production systems, and regions will be most affected by climate shocks. We assumed, following Smith et al. (2013), that increased temperatures by 2050 would result in increased demand of water by crops and reduced yields of most crops due to heat stress and harsher growing conditions. Given uncertainty of the impact of climate change in East Africa, which will determine Nile water flows into Egypt, we define three climate change scenarios: Scenario 1 assumes increased water flows into Egypt as the result of a wetter climate in East Africa; while scenarios 2 and 3 assume a small and a large reduction in water flows.

Results of simulations show that reduction of Nile water flows and changes in crop yields as a result of climate change are likely to have significant negative effects on agricultural production in Egypt. In our simulations, climate change reduces output, labor demand, and harvested area. However, the impact of these changes will affect household types very differently. Impacts on output are positive or relatively small on capitalized producers in Lower Egypt, while small and average household types producing field crops in Upper Egypt would suffer the highest negative impacts. These negative impacts on output and harvested area, however, would not affect household incomes, because output losses are compensated by projected increase in food prices that result from reduced production and a restrictive import policy. Of the seven household types identified in this study, capitalized farmers and average (smallholder) households with diversified production systems of field and high-value seem to be the most resilient.

Our results suggest that to mitigate the risks and possible future impacts of climate change, the country will need to move away from policies supporting production of cereals and water-inefficient crops. Possible strategies to follow include diversification of production into water-efficient high-value crops, like onion, potato, and tomato; reducing the area of major staples, like wheat and rice; promote more efficient production systems of field crops, including clover-livestock-maize production systems and crops that add value per feddan and water used; facilitate improved access to capital and markets for skilled resource-poor producers; and create opportunities for off-farm employment and income for smallholders that currently are using resources inefficiently and with limited possibilities to change to more efficient systems.

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