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Spice Price Spikes: Simulating Impacts of Saffron Price Volatility in a Gendered Local Economy-Wide Model

MATEUSZ FILIPSKI [a], ABDELLAH ABOUDRARE [b], TRAVIS J. LYBBERT [c] and J. EDWARD TAYLOR [c,*]

[a] *International Food Policy Research Institute, USA*
[b] *Ecole Nationale d'Agriculture de Meknès, Morocco*
[c] *University of California at Davis, USA*

Summary. — Access to international markets provides smallholders with unprecedented opportunities, but also exposes them to world market whims. We use a local economy-wide impact evaluation (LEWIE) model to analyze how the recent global saffron-price variability affected Morocco's Taliouine–Taznakht region, a specialized agro-export economy with a stark gender division of labor. Prices of saffron increased by 71% per year over the 2007–09 period before falling quickly back to their trend. Our modeling approach allows us to simulate such shocks and evaluate impacts not only on producers but also on the local economies around them. In our simulations, positive price-shocks and increases in productivity both cause large reallocations of labor resources, particularly for female workers at harvest time. We use Monte-Carlo simulations to evaluate how saffron-price variance affects the economy. Female wage income is especially sensitive to global price variability: a 100% increase in saffron-price variance leads to 133% increase in female wage income variance, but only 36% for males. Accounting for general-equilibrium effects is critical for understanding the ramifications of exposure to export price volatility in poor economies.

Key words — impact evaluation, price volatility, gender, market integration, Africa, Morocco

1. INTRODUCTION

The international market for high-value boutique food products has exploded in recent years. Innovations in certification programs (e.g., fair trade, organic), policy emphasis on value chain approaches to growth in agro-food sectors, widespread NGO support for interventions to improve smallholder profitability, and aggressive marketing by both general and specialty retail chains have combined to create an unprecedented proliferation of differentiated and specialized products from around the world in European and North American markets. Entire aisles in many supermarkets are now dedicated to these boutique food products, which can often be traced to development efforts linking smallholder producers to high-value international markets. Integration with specialty export markets opens up new economic opportunities, but it also exposes producers and the economies of which they are part to the whims of international markets and price volatility. Absent insurance or other interventions to smooth prices, local economies have to adjust to recurring price shocks.

We study the impacts of global saffron price volatility on a saffron-producing economy in Morocco, using unique micro-household data and local economy-wide modeling methods (Taylor & Filipski, 2014). The model we use could be applied to any smallholder cash-crop producing rural economy, but saffron and rural Morocco provide an emblematic case. Taliouine–Taznakht is a specialized agro-export economy heavily dependent on world markets it cannot influence. Production involves a very labor-intensive process (saffron harvesting), and female wage workers constitute a well-defined group of stakeholders that depends almost exclusively on saffron employment for income. These stark features make it an ideal case to study how impacts of price volatility ripple through an economy by way of general-equilibrium effects, and how different actors are exposed to those effects. Further, the recent fluctuations in the price of saffron have been vertiginous.

From 2006 to 2009, the international saffron price more than tripled then collapsed back to its historical average faster than it had risen—a pattern mirrored in saffron prices in rural Morocco. While food prices spiked worldwide during this same period, the factors driving the saffron market are distinct from those driving general food markets. Iran produces the vast majority of the world's saffron, and Spanish wholesalers control much of the international saffron trade. Together, this market power at the production and wholesale levels shapes the international saffron market. Poor production in Iran in the late 2000 s appears to be the main cause of the saffron price spike (Dubois, 2010).

In Taliouine–Taznakht, saffron represents 70% of farm income, and 40% of all income (Aboudrare *et al.*, 2014). Beyond the farmers themselves, the workers they hire and the traders they buy goods and services from are all deeply affected by the saffron economy. High prices were seen as a huge opportunity and triggered significant investment in the sector (in particular in enhanced irrigation technology, as

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water is by far the largest constraint to production).[1] However, the boon did not last.

A boom and bust of unprecedented magnitude can have major consequences for rural livelihoods in saffron-producing regions. A pronounced and rapid appreciation of saffron prices for three consecutive years is likely to lead farmers to shift toward saffron production. One would expect a price collapse to have the opposite effect. Meanwhile, local economy-wide linkages transmit the impacts of the price boom/bust from saffron-producing households to others within the local economy. The prices of local goods and services, the wage rate, the rental rate on land, are all intimately linked to saffron prices. Thus volatility in the price of the spice can translate into instability throughout the local economy.

Inter-temporal linkages transmit impacts across seasons, as well. Saffron, the dearest spice in the world, is produced by cultivating saffron crocus flowers (*crocus sativus*), painstakingly removing their stigmas, and carefully drying them. In this sequential production process, the value of flowers is a derived value linking the harvest and pre-harvest seasons. In the mountainous region of Taliouine–Taznakht in Morocco, cultivation is a male-dominated activity, while women are almost exclusively responsible for the tedious process of harvesting the flowers and delicately removing the crocus stigmas—work that must be accomplished in a very compressed and intense timespan of a few weeks.[2]

Because of the structure and gender division of labor in traditional saffron production, international market shocks potentially affect gender and intra-household dynamics. A high demand for female wage labor at harvest time may divert women from the non-market activities they traditionally perform, including child rearing and housework. The demand for female labor in these domestic activities, in turn, may constrain the saffron-supply response to higher world prices, in much the same way that missing product markets limit market supply response in agricultural household models (de Janvry *et al.*, 1991; Taylor & Adelman, 2003).[3]

Pronounced and rapid appreciation (or depreciation) of saffron prices potentially has far-reaching impacts in a region that depends heavily on saffron production for cash income. Saffron provides wage work opportunities for many, and for most women saffron harvesting is the only option for cash income. Saffron prices influence the incomes, but also the expenditures, of farmers and farm workers. Local businesses thrive or fail with the saffron economy. Combined, the rapid succession of a boom and bust of unprecedented amplitude represents a dizzying shift in incentives for the local economy, and they raise the question of how changes in the distribution (not just level) of prices impact a poor agricultural export economy. The extent to which markets can adjust to the shocks will determine how different actors are affected by these shifts.

The question of smallholder integration to world markets has been researched extensively in the economic literature. Economists have studied how participation in cash crop markets can provide smallholders a pathway out of poverty: growing tobacco in Malawi (Orr, 2000) or fair trade certified coffee in Nicaragua (Bacon, 2005) or pineapples in Ghana (Takane, 2004) have all shown potential to generate positive impacts on farmers. On the other hand, the vulnerability induced by dependency on the mainstream markets was also pointed out (Valkila, 2009). Whether world markets are more or less volatile than domestic markets will shape the impact economic opening (Winters, 2002). The role of risk in smallhoders' decision to engage in cash crop production or not is also well-understood (Fafchamps, 1992). But while the opportunities and risks related to cash crop production by smallholders have been well documented both theoretically and empirically, a majority of this research focuses on producer households alone and pays little attention to spillovers and general equilibrium effects. By adopting an economy-wide perspective, our research sheds light on the economic linkages that transmit world market shocks beyond smallholders themselves and provides a consistent framework to assess them. Our focus on volatility is, as far as we know, unique within the local economy-wide modeling literature. Finally, by distinguishing labor by gender we are able to highlight the differential vulnerability to price-volatility of male and female workers when labor markets are segregated.

We design a local economy-wide impact evaluation (LEWIE) model to uncover the impacts of global saffron price variability on the rural economy and the role of general-equilibrium adjustments in transmitting this variability to local economic outcomes. It extends the model described in Taylor and Filipski (2014) to analyze impacts of price shocks. Our model is tailored to the specificities of the saffron production process, in particular, a highly seasonal and gender-biased labor demand. It also incorporates the non-monetized economy, which represents a substantial burden on the time use of women in the region. To our knowledge, this is the first attempt to formally model the local economy-wide impacts of an agricultural export price boom and the first to capture seasonal linkages in a LEWIE model. We use the model to evaluate the transmission of impacts of the saffron-price boom and bust through the local economy, across seasons and households, and between genders. We simulate the impacts of three types of shocks to the economy observed in recent years in Taliouine–Taznakht: (1) a saffron price shock (increase or decrease), (2) investments in saffron production-enhancing technology, and (3) an increase in the variance of the saffron price distribution.

Our simulation findings reveal that an increase in the global price of saffron leads to a significant reallocation of labor to saffron production in both the cultivation and harvest seasons. It stimulates the labor market, as larger producers hire workers from smallholder households. Workers of both genders are put to work, but males are disproportionately affected in the cultivation season and females at harvest time. Women's time devoted to childcare and other reproduction activities falls at harvest time and increases in the cultivation period. Increases in flower yields create labor bottlenecks at harvest time, resulting in a high demand for female labor to process flowers. Increasing volatility of saffron prices has different impacts on the variability of factor use, production, and incomes. Households are able to buffer the extent to which saffron-price variability translates into income variability, but with high amplitudes in factor-use and production responses. Wage incomes of females are much more volatile in the face of saffron price variability than wage incomes for males.

2. BACKGROUND AND THEORY

(a) *Saffron production*

The saffron crocus can grow under a relatively wide range of climates; however, production of good quality saffron requires specific conditions: soils cannot be too humid or too fertile, rain cannot fall during the flowering season, and temperatures must remain high (Madan, Kapur, & Gupta, 1966). The region of Taliouine, Morocco, has produced saffron for centuries, but it is a more recent crop for the neighboring region of Taznakht. The two regions, respectively, planted 565 and 105 hectares in saffron in 2010 (Aboudrare, Aw-Hassan, & Lybbert, 2014). Compared to worldwide saffron production, the production in this region is relatively modest. Most of the world supply of saffron comes from Iran, 80% to 95% depending on the year and source (Ghorbani, 2006; Kafi *et al.*, 2006). In addition to the Taliouine–Taznakht region of Morocco, which accounts for about 1.5% of world supply (Dubois, 2010), other producers include Greece and the Kashmir region of India. Although the region provides but a small share of the world supply, saffron is the pillar of the Taliouine–Taznakht economy. Saffron production represents 40% of all incomes, and wage-work in saffron fields another 20% (Aboudrare *et al.*, 2014).

Saffron is a highly labor-intensive crop. It is traditionally grown in small, flat plots that may be flood-irrigated. Farmers plant crocus bulbs in these small plots. Bulbs produce flowers for up to seven years, with peak harvests in the third and fourth years. Plots are thus rotated and replanted every 5–7 years, with plantation beginning in September. Plots need to be watered regularly in the vegetative period, and about once a week around the time of flowering, such that in the absence of rains irrigation is crucial. (Dubois, 2010; Aziz & Sadok, 2015). Water is the single most important constraint to yields and the expansion of production in the region. By contrast, fertilizer requirements are low: farmers apply manure twice a year, but the use of commercial fertilizer is not recommended, nor is the use of any pesticides (Aziz & Sadok, 2015).

Labor requirements are gender-specific throughout the production process: males are in charge of bulb harvesting, soil preparation, fertilization and irrigation, while women principally work on pruning leaves, picking the flowers, and harvesting their stigmas. Most of the labor requirements for female tasks are satisfied by family labor, but high requirements at harvest time prompt the emergence of a spot labor market for females.

The harvest lasts less than a month, from the end of October to mid-November, but it mobilizes about 60% of the total labor input to the activity (Dubois, 2010). Groups of workers—predominantly women and girls—pick flowers very early in the morning before the sun withers the stigmas. They then spend the rest of the day extracting stigmas from the harvested flowers. In most households, family labor is exclusively engaged in saffron production during this intense harvest period. Households that produce substantial saffron rely heavily on a thriving local labor market for female workers during harvest. Figure 1 illustrates the important role of female labor in saffron production in the Taliouine–Taznakht region, particularly in the harvest season. Overall, female labor contributes about 30% of the total value added generated over the course of the production process.

Because saffron production provides one of the only wage labor opportunities for females, it is instrumental to women's ability to secure cash income, with potentially important consequences for family dynamics. The high demand for female wage labor may create a strain on women's time, possibly diverting women from other activities they traditionally perform, such as child rearing or housework. As those activities are not directly income-generating, they usually are overlooked in modeling the impacts of market shocks in rural economies. The female labor market is highly seasonal; it exists only at harvest time, with very little wage-work available to women the rest of the year.

Until recently, most of the saffron produced in the Taliouine–Taznakht region was sold in local markets. Under the proper conditions, saffron can be stored for several months without losing its potency, so many households would stagger their saffron sales over the course of nearly a year as needs for cash arose. Since 2008, there have been efforts to organize producers into cooperatives, improve the production and marketing of saffron in the region, and directly link smallholder producers with high-value international saffron markets. However, in 2010, less than 40% of all saffron was sold through formal channels (Dubois, 2010).

Even before these efforts, prices in local saffron markets closely tracked international markets because of the activities of Spanish traders. Beginning in 1991, the average real saffron price in local markets in Taliouine was about 4,000 Moroccan Dirhams (MAD) per kilogram (~$40/kg). Beginning in 2007, however, these prices rapidly increased more than threefold. After peaking at 14,000 MAD/kg in 2009 ($750/kg), the price collapsed back to just above its historical average of about 6,000 MAD/kg (see Figure 2).[4]

(b) *Seasonality and Gender: an illustrative theoretical model*

Before describing the full LEWIE model, is it useful to gain some intuition and theoretical perspective with an illustrative analytical model. The few equations we present in this section are meant to illustrate the ways in which price shocks to a crop might affect a smallholder household, when production of that crop (here: saffron) is a highly gendered and seasonal production process.

Consider a household that gets utility from consuming up to I tradable goods (c_i, $i = 1, \ldots, I$) and a domestic good (in Becker (1965) terms, a "z-good"). The domestic good (or

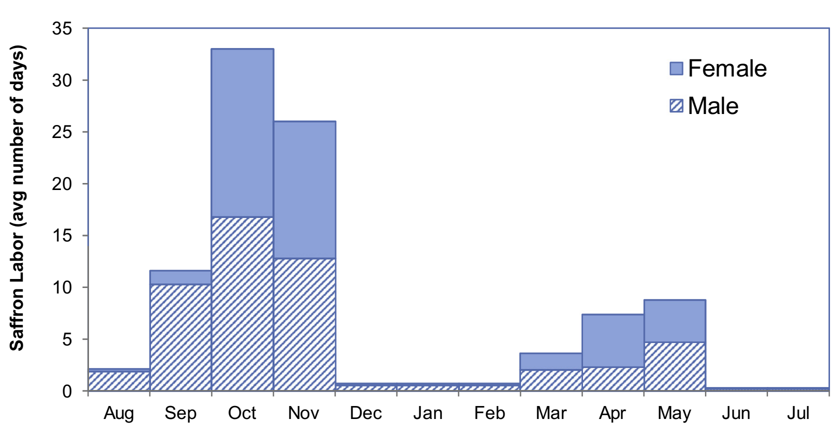

Figure 1. *Saffron labor inputs by month and by gender in the Taliouine–Taznakht region of Morocco. Source: Aboudrare et al. (2014).*

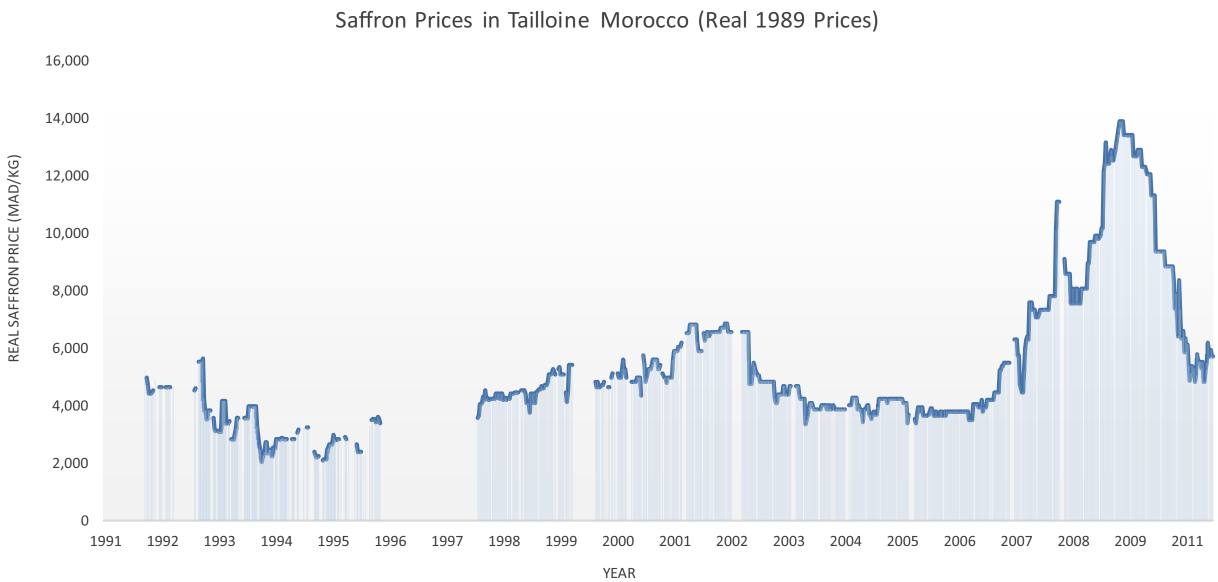

Figure 2. *Evolution of real (1989) saffron prices in Tallioune, Morocco. Source: ORMVAO (2013)*

service) is produced by (primarily female) labor during the saffron flower pre-harvest (*ph*) and harvest (*h*) seasons (z_s, $s = ph,h$):

$$U = U(c_1, \ldots, c_I, z_{ph}, z_h) \quad (1)$$

Utility is maximized subject to a potential or full-income constraint, which states that consumption cannot exceed the household's full income, Y^f. Full income includes profits from saffron production plus the value of the household's time endowment. Let: p_H denote the global saffron price; Q_H, saffron output; Q_F, crocus flower output; K, land in flower production; $L_{H,g}$ and $L_{F,g}$ the demand for labor by gender g in saffron and flower production, respectively; $w_{s,g}$, wage by gender and season; and $T_{s,g}$, household time endowments. Full income Y^f is expressed as:

$$Y^f = p_H Q_H - w_{h,g} L_{H,g} - w_{ph,g} L_{F,g} + \sum_s \sum_g w_{s,g} T_{s,g} \quad (2)$$

The shadow value on the full-income constraint is λ, the marginal utility of full income. The saffron production function is:

$$Q_H = Q_H(Q_F, L_{H,g}) \quad (3)$$

Saffron flowers are produced using labor and a fixed amount of land with a technology described by:

$$Q_F = Q_F(L_{F,g}, \bar{K}) \quad (4)$$

The final constraint in this illustrative model is a subsistence condition stating that the demand for domestic goods, z_s, cannot exceed the supply, which depends on labor allocated to domestic production:

$$z_s = z_s(L_{z_s,g}, s = h, ph) \quad (5)$$

The shadow value on this constraint is μ_s, the marginal utility of the domestic good, which may vary between seasons.

Maximizing utility subject to these constraints yields a number of first-order conditions that help illustrate the how saffron prices affect the economy, including:

$$\rho_F = p_H \frac{\partial Q_H}{\partial Q_F} = p_H \phi \quad (6)$$

The shadow price of crocus flowers is the product of the saffron price with the marginal product of crocus flowers in saffron production. If the latter is a fixed Leontief relationship, such that an amount ϕ of saffron is extracted per flower, this price is exogenous. It depends directly on the global saffron price.

$$p_H \varphi \frac{\partial Q_F}{\partial L_{F,g}} = w_{ph,g} \quad (7)$$

Households allocate labor to flower cultivation to equate the marginal impact on saffron revenue with the pre-harvest wage. The marginal revenue impact is the product of the saffron price, saffron extracted per flower, and the marginal product of labor in flower production.

$$\rho_{z_s} \frac{\partial z_s}{\partial L_{z_s,g}} = w_{s,g} \quad (8)$$

The marginal value product of each gender's time in domestic production equals the wage. The shadow price of the domestic good each season is $\rho_{z_s} = \frac{U_{z_s}}{\lambda} = \frac{\mu_s}{\lambda}$. The domestic good is a household autarkic good; its price equals its marginal utility (the shadow value on the domestic-good constraint) divided by the marginal utility of income.

This simple model, extracted from the full model (described in Appendix A), illustrates the key pathways by which saffron -price shocks impact households. An increase in the saffron price drives up the flower price (Eqn. (6)), stimulating labor demand (and thus output) in flower production (7). The impact on domestic production is ambiguous. There is an income (saffron profit) effect that increases the demand for the domestic good, assuming it is normal. However, the higher demand drives up the price of the domestic good (8), dampening the demand effect.

Increased labor demand in saffron and crocus flower production puts upward pressure on wages, which although exogenous in the household model are endogenous in a general equilibrium model. Gender- and season-specific wages are determined by equating total regional labor supplies and demands. An increased domestic good shadow price may mitigate the demand effect, while higher wages increase the opportunity cost of allocating time to domestic good production.

If the household produces traded goods other than saffron (as they do in our full model), the outcome could be a local version of the Dutch disease, as households shift time from other tradables to saffron, flowers, and domestic goods. The relative impacts on wages and labor demand by gender naturally depend on the labor-gender intensity of flower, harvesting, domestic good, and other production.

In short, the impacts of the saffron-price shock are analytically ambiguous, a compelling reason to construct a LEWIE model in order to evaluate these impacts. Creating a full-blown LEWIE requires several enhancements to this model, such as adding production functions other than saffron alone and other households to interact with. Most importantly, in order to be computable the LEWIE needs to specify functional forms for the utility and production equations (such as (1), (3), (4), (5)). We describe model and calibration specifics in the next section.

3. A LEWIE MODEL WITH SEASONALITY AND GENDERED LABOR MARKETS

A LEWIE model is an applied general equilibrium (GE) model with a local twist: it is a system of equations describing the functioning of a local or regional economy, accounting for all commodity and factor markets (hence "general" as opposed to "partial" models focusing on a single market). It includes production and consumption functions for all commodities and services, balanced by market clearing equations that define prices for all tradable commodities and factors (hence "equilibrium") and net trade for tradables. LEWIE models, in contrast to the majority of applied and computable general equilibrium (CGE) models, are implemented on a relatively small scale (a local economy, which can be a village, region, island, etc.). They are rooted in the tradition of agricultural household models (Singh, Squire, & Strauss, 1986) and village models (Taylor & Adelman, 1996), disaggregating local activities, actors and markets and constructed using local data, usually at the household level (Taylor & Filipski, 2014; Taylor, 2013; Thome, Filipski, Kagin, Taylor, & Davis, 2013).

The Saffron LEWIE model is an economy-wide model at a regional scale. It portrays the economic behavior of households in the Taliouine–Taznakht region: what the households produce, how they produce it, how they trade with each other and with the rest of the world, how they earn money in the labor market, and how they spend their income. The complete model, programed in GAMS, is available as an online appendix, along with the data input sheet.

GE modeling has been a popular tool to analyze ways in which macroeconomic shocks ripple through economies ever since Leontief laid the groundwork for input–output analysis (Leontief, 1951). Cast at various geographic levels of analysis, GE models have been used to highlight the complex and interrelated impacts of economic shocks ranging from trade liberalization (Sadoulet & De Janvry, 1992; De Melo, 1988; Hinojosa-Ojeda, Robinson, & Lewis, 1995), to tax policy (Berck & Dabalen, 1995; Vellinga, 2011), migration (Brücker & Kohlhaas, 2004; Sussangkarn, 1996; Taylor & Dyer, 2009), and climate change (Hertel, Burke, & Lobell, 2010), among many other examples (see Burfischer, 2011). Often, GE models are able to provide insights into impacts where other economic methods are impractical or infeasible.

The questions we ask in this paper—relating to saffron price shocks and local labor markets—are of the kind best answered through a GE lens on a local scale. A price shock enters the local economy via saffron producers, who adjust in complex ways (as in our theoretical illustration, above) and, in the process, transmit impacts to others in the economy, from the hired laborers who work their fields to the shopkeepers who sell them groceries. The economy of Taliouine–Taznakht is land-constrained and relatively isolated from the rest of the world when it comes to labor markets, so any shifts in demand or supply of factors are likely be reflected in local wages and rents; these potentially alter incentives for everyone in the region. Concentrating productive resources into the saffron activity requires shifting resources away from other activities. A local GE framework is uniquely suited to highlighting these trade-offs. Identifying the impacts of saffron price shocks with experimental or econometric methods would require data that do not exist. A randomized controlled trial obviously is not feasible, and time-series data from household surveys spanning the length of the price boom are not available.

The flexibility of the LEWIE framework allows us to tailor our modeling to the specificities of the saffron economy, including the gendered nature of the production process and seasonality of production activities and labor demand.

(a) *Saffron production specificities in a LEWIE context*

The stark division of labor between males and females is a defining characteristic of saffron production, and it is central to our LEWIE model. Understanding the labor impacts of the saffron boom necessitates distinguishing female from male labor. In addition, the saffron harvest competes with domestic care for female time. "Engendering" the model requires modifying the standard LEWIE approach in two ways: first, by treating male and female labor as separate inputs in production activities; and second, by featuring household reproduction activities explicitly.

General equilibrium models with gendered features were pioneered by Fontana and Wood (2000) and have since been applied in multiple studies (Fofana, Cockburn, Decaluwé, Chitiga, & Mabugu 2005; Fontana, 2002, 2004; Sinha & Sangeeta 2003; Terra, Bucheli, & Estrades, 2009). Filipski, Taylor, and Msangi (2011), which focuses on rural activities and time allocation in the Dominican Republic, uses a model that shares some of the features of the saffron LEWIE presented in this paper. It also provides a review of the gendered CGE literature.

While a gender division of labor in agriculture is not uncommon, saffron presents two specificities. First, the saffron gendered division of labor is by task, not by crop or plot. This contrasts with the frequently observed situation in which females are in charge of growing food crops and males cash crops (Doss, 2002), or where females and males control different plots (Udry, 1996). Second, the seasonal flash market for female wage workers is a unique consequence of the female-labor-intensive nature of the saffron harvest. Therefore, the seasonality of saffron production is directly linked to a gender disaggregation of labor.

We are not aware of applied GE models with seasonality, but from a mathematical point of view it is fairly straightforward. In our LEWIE model, like in the theoretical illustration above, we treat the two seasons as sequential production stages (Antle, 1983). In the cultivation season, households produce flowers. In the harvest period, the flowers, along with labor, are inputs into the production of saffron. Flowers, then, represent a constraint on saffron production: no more saffron can be produced than is available from the stigma of flowers grown in the pre-harvest period. The price of flowers is a shadow price, determined by the marginal value product of flowers in second-period saffron production. It links the two periods in our model. The market price of saffron, which is exogenous, influences the shadow price of flowers—a temporal analog to the way in which market prices influence shadow prices of subsistence crops (Dyer, Boucher, & Taylor, 2006).

(b) *Modeling specifics*

The building blocks of LEWIE are agricultural household models describing the economic behavior of households in the economy (Singh *et al.*, 1986; see Appendix A). Households allocate their resources to equate marginal value products of inputs across production and reproduction activities. On the consumption side, they allocate income to equate marginal rates of substitution (MRS) with corresponding price (or in the case of household autarkic goods, shadow-price) ratios. First-order conditions determine input demands as well as output. Factor incomes, together with any exogenous income, set the budget constraint on household consumption. Households maximize utility subject to this budget constraint; this determines consumption demands. The difference between output and consumption determines marketed surplus. In these respects, household models in our LEWIE for Taliouine–Taznakht are similar to any generalized household-farm model with multiple production and income activities, as in De Janvry, Fafchamps, and Sadoulet (1991).

(i) *Actors*

All village households are grouped into three categories, based on their labor trading status for saffron production in the year of the survey: those who hire saffron labor in, those who neither hire it in nor out, and those who hire it out. (The second group is thus comprised of self-reliant saffron producers and some households with no direct connections to saffron). Table 1 describes those three groups. Each group has its own set of behavioral equations in the model; both production and consumption behavior are household-group-specific.

(ii) *Activities*

We model saffron production as two linked activities: the production of saffron crocus flowers (*crocus sativus*), and the harvest of stigmas out of the flowers. In addition, we distinguish three types of non-saffron activities: agriculture, livestock, and all non-agricultural activities (services, crafts, etc.). Finally, in each of the two seasons we model two domestic activities, care and leisure, where care refers to household chores, cooking, child rearing, and home improvement.

(iii) *Production*

Production activities require factors and intermediate inputs. Factors in the model include land, capital, commercial inputs, and four types of labor distinguished by gender and season. Intermediate inputs are produced by one activity and used by another, such as feed for cattle or, most notably, crocus flowers used in the saffron harvest. The different activities and the factors and inputs they use are listed in Table 2.

Factors and intermediate inputs are treated differently in the production function. Factors create value added (via a Cobb–Douglas process). This means that all factors are substitutable with elasticity of substitution equal to 1.[5] Intermediate inputs do not create value added but must be used in fixed proportion to output. Intermediate inputs follow a Leontief process because, unlike factors, they are not substitutable. This specification is particularly appropriate to a two-season saffron activity: crocus flowers (produced in the cultivation season) are intermediate inputs into saffron production (the harvest season). One can farm the same plot of land more intensively and produce more crocus flowers (i.e., substitute land for labor); however, one cannot harvest the same flower more intensively to obtain more saffron out of it (i.e., substitute labor for flowers).

We distinguish between labor in the harvest season and in the rest of the year (which we call the cultivation season). With the added gender distinction, the model features four pools of laborers: males in the harvest season, females in the harvest season, males in the cultivation season, and females in the cultivation season. Some activities draw labor from all four pools (for instance, livestock production, which requires year-round attention); others use only one type of labor or another (the saffron harvest only uses harvest-season workers, male and female). This allows the model to simulate labor-market outcomes, including labor shortages that may occur at harvest time or the choice females face between wage work and care activities.

Table 3 provides insight into how we treat seasonal activities and "non-productive" activities. We divide saffron production into a "flower production" activity (cultivation) and a "saffron production" (harvest), each of which only uses labor in the corresponding season. The flower production activity combines labor with land, capital, and purchased inputs to grow crocus flowers. The saffron harvest is similar to a pure resource extraction activity: it only uses labor to get saffron out of the existing flowers.

Agriculture, livestock, and non-agricultural activities are not seasonal, at least in the sense of the seasons in our model, as households may have some flexibility in allocating time to them. It is conceivable that a household can choose to till the soil or apply fertilizer at a time that does not overlap with the saffron harvest. Leisure and care activities, on the other hand, are separated by season to reflect the fact that activities such as resting, preparing meals, or helping children with their homework are not readily fungible across time. They use no land, capital, or inputs; they simply compete with other activities for limited family time. Males and females allocate time to leisure, but our data indicate clearly that only females contribute to the care activity as we define it.

(iv) *Consumption*

Households spend income on goods and services produced by village activities and an additional category of items supplied by outside markets. The domestic goods, care and leisure, are autarkic goods: they can only be "consumed" in

Table 1. *Description of household groups in the model*

HH group	Labor trading status for saffron activity	Sample size	Proportions (weighted)	Represented population
1	Hire labor in for saffron	109	41%	2945
2	Not involved in saffron labor markets	113	45%	3232
3	Hire labor out for saffron	42	14%	1005
Total		264	100%	7182

Table 2. *Activities in the model and input or factor use*

	Activities								
	Flower	Saffron	Ag	Livestock	Non-Ag	Care in harvest season	Leisure in harvest season	Care in cultivation season	Leisure in cultivation season
Inputs into each activity									
Commodities									
Flower		x							
Saffron									
Ag				x					
Livestock									
Non-ag									
Factors									
Land	x		x	x					
Capital	x		x	x	x				
Male Labor – harvest season		x	x	x	x		x		
Female Labor – harvest season		x	x	x	x	x	x		
Male Labor – cultivation season	x		x	x	x				x
Female Labor – cultivation season	x		x	x	x			x	x
Purchased inputs	x		x	x	x				
Total Value of Production*	1,601,687	2,731,097	2,308,370	5,257,764	505,361	137,295	16,475	1,473,635	921,022

x marks which factors or inputs are used by each activity. *: for care and leisure value = opportunity cost of time.

Table 3. *Market closure for commodities and factors*

Commodities	Market closure		
	Autarkik	Regional market	Integrated Market*
Flower		x	
Saffron			x
Ag			x
Livestock			x
Non-ag			x
Imported goods			x
Care in harvest season	x		
Leisure in harvest season	x		
Care in preharvest season	x		
Leisure in preharvest season	x		
Factors	Fixed factor	Regional market	Integrated Market*
Land	x		
Capital	x		
Male Labor – harvest season		x	
Female Labor – harvest season		x	
Male Labor – preharvest season		x	
Female Labor – preharvest season		x	
Purchased input			x

* Integrated markets refer to goods and factors which are be traded outside the region at exogenously determined prices.

the household that "produces" them, much like a Becker z-good. They are valued at the opportunity cost of time put into them, valued at market wages that vary between genders and across seasons. Household utility functions follow a Stone-Geary schedule with consumption minima for leisure and care. Stone-Geary functional forms are similar to Cobb-Douglas, but allow to define minimal consumption requirements. This is useful when modeling domestic goods, as humans all require a certain minimal amount of time to dedicate to sleep, hygiene, etc. As long as those minima are satisfied, the households are able to substitute between the goods they consume with an elasticity of substitution equal to 1. Domestic goods and consumption items are all substitutable and treated alike: each will be consumed in quantities that equate the marginal utility to the (shadow) price.

(v) *Markets and closure rules*

The model links households through markets, which permit intra-regional trade in commodities and labor. However, not all goods and factors are tradable in all markets. For each good and factor, closure rules determine where markets clear and prices or wages are determined. Table 3 summarizes those assumptions.

We distinguish among three possible levels for commodity trade: autarkic, tradable within regional markets, and tradable outside of the region ("integrated" with national or international markets). An autarkic commodity is a subsistence good: the household must produce it in order to satisfy its own demand, and, once produced, it cannot be sold. Leisure and care are subsistence goods by definition: one cannot pay a neighbor to take a nap on one's behalf, cook a homecooked meal, or provide motherly care to children (purchased meals and foster care services do enter the model in the "non-agricultural activities" category; they are imperfectly substitutable for care as depicted by the utility function).

Regional markets clear locally. Households can sell local goods in the Taliouine–Taznakht area, but they cannot export them outside; the prices of these goods depend on local supply and demand. Only saffron flowers are treated in this way: a crocus patch cannot be transported out of the village for harvest, but a labor-constrained household might sell its patch at harvest time (though our data indicate that it is more likely to hire workers and supervise their work).

Commodities traded outside the region can be imported or exported outside the region at a fixed, exogenously determined price ("integrated" markets). From the region's perspective, it makes no difference whether this price is fixed on national or international markets, thus nationally and internationally tradable goods are treated equally in our model. Agricultural production, livestock, non-agricultural production, saffron, and imported goods in our model are all traded in such integrated markets: regional production does not affect the price.

There are also three levels of market closure for factors: fixed factors, regionally tradable, and tradable outside the region. Fixed factors cannot be traded outside the household and are activity specific: they cannot be reallocated between activities even within the household. Land and capital are fixed factors in the model, implicitly with a household-level "shadow price." Labor is treated as regionally tradable with a local wage, reflecting poor integration of local labor markets with the rest of Morocco. Soaring wages at harvest time are an indication of poor labor-market integration. Purchased inputs are traded on an integrated market (in fact, there is no local production); thus they have a fixed, exogenously determined price in the model.

(c) *Data and calibration*

(i) *Household survey data from Taliouine–Taznakht*

Our model was calibrated using household data from the region of Taliouine–Taznakht, which we collected in collaboration with ICARDA, USAID and ORMVAO (ICARDA, 2010). Data were gathered in the spring of 2010 from 264 households in six rural districts in the region, chosen to be representative of the region. Two to four villages (or *douar*) were randomly selected within each district (a total of 17 *douar*); households were randomly chosen within each *douar* in numbers proportional to population weights. Two questionnaires were administered: one for males and one for females. In households with married heads, the household head and spouse were interviewed separately. Respondents were interviewed in their local language (*Amazigh*). The dataset collected extensive data on farm production, particularly the saffron activity, including the production process, output, and income. It also gathered data on wage work in saffron plots and consumption expenditures. Importantly for this modeling exercise, a time-use module collected the time allotted by household members to a range of productive activities (agricultural or not), reproductive and personal care activities (child care, water collection, cooking, sleep, bathing, etc.) as well as leisure activities (rest, social events, watching television, etc.).

Table 4 provides a description of our data by rural district. The survey sites span a range of agro-ecological conditions due to their varied altitudes, from 1500 m to more than 2000 m above sea-level. Some have been producing saffron for centuries and others started as late as the 1980s. The total number of households in the districts at the time of data collection was 945, of which 28% are included in our sample.

Saffron cultivation takes place on very small plots. The limiting factor is water availability, not land. While only 5% of our sample is landless, the average saffron plot size varies from 536 m^2 to 1645 m^2 (0.16 ha). The average production volume per cultivating household doubled during 1999–2009, from 235 g to 450 g. In all districts, saffron accounts for more than half of total agricultural income, 71.5% on average. The remainder of agricultural production is mostly barley and some vegetable crops (Aboudrare *et al.*, 2014). While much of that is consumed at home, the quantities are insufficient to ensure subsistence—they purchase food from rotating markets using income from saffron. As a whole, the region is a net

Table 4. *Data description by rural district*

	District						
	Askaoune	Siroua	Assais	Agadir Melloul	Sidi Hssain	Iznaguene	Total sample
Characteristics							
Altitude	Over 2000 m		1700 m–1800 m		1500 m–1600 m		
History of Saffron Production[a]	Recent	Recent	Ancient	Ancient	Ancient	Recent	
Population (# households)	266	176	109	74	212	108	**945**
Sampled households (#)	62	43	41	20	56	42	**264**
Descriptive Statistics (Averages)							
Household size (#)	8.4	9.0	7.0	7.7	6.6	9.2	**8.0**
Number of Children (<16 years old)	2.8	2.9	1.7	2.3	1.8	2.0	**2.3**
Age of household head	57	53	62	55	56	56	**56**
Area in saffron (m^2)	903	1436	749	537	749	1646	**814**
Saffron production per household 1999 (kg)	0.108	0.398	0.216	0.093	0.347	0.448	**0.235**
Saffron production per household 2009 (kg)	0.448	0.722	0.303	0.360	0.615	0.662	**0.450**
Household revenue from saffron (MAD)	6919	13,696	3224	7199	9175	10,647	**7055**
Share of total income from Saffron (%)	39.6%	34.7%	34.2%	40.8%	50.2%	41.4%	**40.1%**
Share of agricultural income from Saffron (%)	79.3%	51.1%	67.9%	72.3%	79.8%	55.4%	**71.5%**
Household income (MAD)	17,472	39,470	9427	17,645	18,277	25,717	**17,594**
Gini coefficient for 2009 incomes	0.48	0.49	0.52	0.48	0.61	0.50	**0.56**

Source: Aboudrare *et al.* (2014)
[a] Ancient refers to several centuries, Recent to less than 50 years.

importer of food. The region's dependence on Saffron is remarkable. Saffron production represents 40% of all incomes, making it the largest income source in the area. Further, the second largest source is wage work in saffron plots, responsible for another 20% of total income (Aboudrare *et al.*, 2014).

The region is generally poor—in both absolute terms and relative to much of the rest of Morocco—yearly household incomes average MAD 17,500 (just above 500 dollars per person in PPP terms).[6] Income inequality is high: Gini coefficients all exceed 0.48. However, there are indications that inequality has tended to recede with the expansion of saffron cultivation (Aboudrare *et al.*, 2014). Saffron production creates local spillovers because of its labor intensity; landless households benefit from wage work opportunities in saffron production as well as potentially in linked activities. This underscores the importance of understanding impact channels in the local economy.

(ii) *Model calibration*

Calibrating a model entails finding a set of variable and parameter values that, together, constitute a solution. In most GE applications, researchers use a social accounting matrix (SAM) for calibration, but that is due to convenience rather than necessity. For our Saffron model, we chose to calibrate the model directly, estimating model parameters using household survey data, as in Thome *et al.* (2013). We estimate the parameters of the consumption and production functions using econometrics or statistics, using household production and consumption data. Together with the production volumes and household incomes from the data, these estimated parameters then define a system of inputs, production, incomes, and consumption, and trade which is a base solution to the model.

Factor shares for the saffron activity were estimated econometrically, using a log–log regression of saffron output value per unit of land on labor and purchased input values and a fertilizer dummy. We find that labor accounts for about 65% of the value of output (depending on the households), while purchased inputs and fertilizer account for 13% (though this share was not statistically significant in the regression). The residual 22% is attributed to land. These results highlight the labor-intensity of the saffron production process. We further use precise labor input data in labor hours available from the survey to obtain the contribution of each labor type to value added (cultivation and harvest, female and male). The final input shares used in the model for the saffron production and agricultural production activities are presented in Table 5. All other parameters to the model are presented in the data input sheet in appendix.

Although the survey provides detailed data on saffron production, there are some data gaps with regard to other activities. Factor shares in other productive activities were not available; they had to be approximated with information from other studies.[7] These factor shares were applied to the total production output reported in the survey to determine input values. Once we had computed all factor inputs to "productive" activities, we used the totals to determine the value of labor inputs into "domestic" activities. Data on households' weekly allocation of time in each season provide care-to-labor time-use ratios for females (1.4 care-to-labor ratio in cultivation season, 1.0 in harvest time). Males do not participate in the care economy, but we compute their leisure-to-labor time-use ratios (0.7 in cultivation period, 0.08 at harvest time). Due to weak data on female leisure we could not estimate leisure-to-labor ratios for women. In this model, females are assumed to enjoy half as much leisure as males in harvest season and a quarter as much in the cultivation season.[8]

Table 5. *Factor shares in Saffron and agricultural production*

	Household groups		
	1 Hire labor in for saffron	2 Not involved in saffron labor markets	3 Hire labor out for saffron
Saffron production			
Land	19%	21%	23%
Inputs	11%	12%	13%
Hired males	5%	0%	0%
Hired females	1%	0%	0%
Family males	8%	10%	8%
Family females	5%	6%	6%
Harvest season			
Hired males	4%		
Hired females	6%		
Family males	20%	26%	27%
Family females	20%	24%	23%
Agricultural activity			
Cultivation season (for saffron)			
Land	18%	18%	18%
Capital	4%	4%	4%
Inputs	4%	4%	4%
Hired males	27%	27%	27%
Hired females	0%	0%	0%
Family males	18%	18%	18%
Family females	18%	18%	18%
Harvest season (for saffron)			
Land	2%	2%	2%
Capital	1%	1%	1%
Inputs	1%	1%	1%
Hired males	3%	3%	3%
Hired females	0%	0%	0%
Family males	2%	2%	2%
Family females	2%	2%	2%

The total value of hired labor used in production is distributed to households based on their reported wage income. The survey data also provide information on income from exogenous sources such as remittances or gifts. These values let us compute total household income. Expenditure shares from the survey were computed using household purchases and subsistence production valued at locally observed prices. We used the average shares applied to total household income to calibrate the consumption function parameters for all consumed goods and services (except leisure and care, for which consumption is equal to production, i.e. the value of time inputs).

The baseline variable and parameter values for the model were arranged in a table (on-line appendix) that was read directly into the LEWIE model, programed in GAMS.

4. LEWIE SIMULATIONS AND RESULTS

The set of calibration values for variables and parameters constitutes a base solution to the system of equations constituting the model. Simulations with this model involve altering parameters in the system of equations then re-solving to obtain a new equilibrium—the solution is found using a solver algorithm embedded in the GAMS software.[9] Observing how model variables adjust to keep the economy in equilibrium gives us insight into how real shocks might affect the economy.

We use our LEWIE model to simulate three types of shocks to the saffron economy: (1) a shock to saffron price levels, (2) a change in production technology, and (3) an increase in the variance of the price distribution. All three simulations are inspired by the recent events observed in Taliouine–Taznakht.

(a) *Price simulations*

We simulate a 71% increase in the price of saffron, which was the average yearly change in real saffron prices in the years 2007–-09. The results of those price simulations are summarized in Table 6 (central panel). The shock we model is positive and evokes the rapid and pronounced saffron price boom which happened over those three years, but a similar exercise can be performed with a negative price shock (in the spirit of the bust that followed). This would produce a response that is largely symmetric but of somewhat different magnitudes, since the model is non-linear. [10]

The top part of Table 6 (section A) reports the reallocation of labor between activities in each season. Households allocate more time to the newly-profitable saffron activity. In the harvest season, they increase their labor input into saffron harvesting (by 389 million MAD). This means increasing output of crocus flowers in the cultivation season (requiring additional labor inputs of 378 million MAD). The stimulus to flower production reflects the inter-temporal linkages at work in this model. Higher labor demand pushes up wages in both seasons, creating negative impacts on the production of tradables (Ag, Livestock, and Non-Ag). While the levels of labor reallocations to saffron activities are roughly equal in both seasons, they represent less of a strain during the flower cultivation period, which lasts much longer than the harvest period. The pressure on labor resources at harvest time is reflected in the large percentage reduction in labor inputs to all other activities, tradable or not. In the cultivation period, increasing labor supply by 67% requires reducing labor inputs to other activities by not more than 32%, but in the harvest period, the reduction ranges from 53% to 70%, depending on the activity. This is also reflected in the local wages (section B): though they barely increase at cultivation time, labor scarcity in harvest season means wages increase almost threefold (148% and 130% for females and males respectively).

The impact on household autarkic goods (care and leisure) is ambiguous and season-dependent. In the harvest season, households neglect leisure in favor of saffron. However, households *increase* leisure in the non-harvest season, by a larger net amount (45 million MAD worth of time). This is due to the income effect of dearer saffron. By demanding more of the leisure activities, households shift time away from tradables production (agriculture, livestock, and non-agricultural goods). Still, a high shadow value of time discourages them from increasing leisure at harvest time. This simulation displays a "catching up on lost sleep after the harvest" effect, an inter-temporal shift in leisure. As for the care activity, it is neglected during the harvest season, but unlike leisure it is hardly compensated for in the cultivation season. This reflects the female-labor intensity of the care activity.

The bottom panel of Table 6 reports changes in labor demand for the three household groups, by gender and season. Recall that household groups are defined according to their labor surplus status in saffron production: group 1 hires laborers on their saffron plots, group 2 does not hire any labor in or out as far as saffron production is concerned, and group 3 hires saffron workers out (to group 1). This is the situation in the base model, but nothing in the model prevents households from departing from their original labor market partic-

Table 6. *Simulation results*

	Initial level		Simulation of 71% saffron price change				Simulation of 10% increase in productivity of cultivation period			
	Cultivation	Harvest	Cultivation		Harvest		Cultivation		Harvest	
			Level change	Percent change	Level change	Percent change	Level change	Percent change	Level change	Percent change
A. Labor reallocation - by activity										
Flower	577	na	388.98	67.4%	na	na	−15.28	−2.6%	na	na
Saffron	Na	1,129	na	na	378	33.4%	na	na	85.41	7.6%
Agriculture	1,429	186	−381.79	−26.7%	−128	−68.5%	−19.41	−1.4%	−28.10	−15.1%
Livestock	1,652	216	−147.59	−8.9%	−131	−60.8%	5.06	0.3%	−29.34	−13.6%
Non-Ag	312	41	−100.21	−32.0%	−29	−70.8%	−6.00	−1.9%	−6.35	−15.6%
Care	1,473	137	45.41	3.1%	−81	−58.9%	13.11	0.9%	−19.43	−14.2%
Leisure	921	16	195.20	21.2%	−9	−53.9%	22.53	2.4%	−2.19	−13.3%
B. Impact on wages										
Females	*1.0*	*1.0*	0.033	3.3%	1.48	148%	−0.005	−0.5%	0.164	16.4%
Males	*1.0*	*1.0*	0.001	0.1%	1.30	130%	−0.01	−1.0%	0.146	14.6%
C. Net Labor Supply – by household (summed across all activities)[a]										
Females										
Saffron employer household	−18	−61	−33	180.5%	−50	81.7%	−2	10.7%	−10	16.2%
Uninvolved household	0	0	25	na	32	na	2	na	6	na
Saffron worker household	18	61	8	43.7%	18	30.1%	0	0.3%	4	6.0%
Males[b]										
Saffron employer household	174	8	−84	−48.2%	−50	−617.0%	−2	−1.3%	−9	−113.4%
Uninvolved household	−178	−13	64	−35.8%	30	−226.9%	3	−1.5%	5	−41.2%
Saffron worker household	4	5	20	454.3%	20	387.5%	0	−11.0%	4	72.6%

Note: Amounts expressed in thousands of MAD worth of labor before wage readjustment.
Source: Author simulations.
[a] Negative net labor supply means household hires labor in.
[b] Males are often employed in other activities than saffron, household were categorized according to their participation to saffron labor market only.

ipation status once a shock is simulated. The results in Table 6 reveal that the price increase stimulates the labor market for both genders and in both seasons. Most reallocation of male labor occurs in the cultivation season, while the opposite is the case for female labor. Since males are not usually hired for harvesting, the harvest-time reallocation of labor represents a larger change in percentage terms for males. The case of group 2 household females is most interesting: while they did not participate in the labor market in the base model, the high saffron prices pull them into the labor market. This illustrates the opportunities embodied in the saffron boom.

(b) *Technological change*

The Taliouine–Taznakht region is fairly arid and unfit for many crops. Water is an important constraint. Saffron yields depend critically on the type of irrigation and the amount of water available. Drip irrigation can increase crocus flower yields while reducing water use but is not widely used because of high fixed costs and scale economies The saffron boom stimulated technological change, including the adoption of drip irrigation. Unfortunately, there are no comprehensive data available to track irrigated area over the price-spike period. However, in the field we observed that irrigation technology was a hot topic of conversation among Taliouine–Taznakht farmers during the price-boom years

We used the model to simulate a 10% increase in productivity in the cultivation season resulting from irrigation or other measures. The two-season structure of the model allows us to highlight the notion of bottleneck. This is inspired by the introduction of drip technology, which dramatically increases yields in the cultivation period but does not alter harvesting efficiency. Formally, we implement this simulation by increasing the shift parameter on the Cobb-Douglas production function for crocus flowers by 10%.

The right-hand side of Table 6 shows the impact on labor allocation patterns across all activities in both seasons. Even though the technological change occurs in the cultivation season, the magnitude of its impacts is much greater in the harvest season. Households are able to reduce their allocation of labor to growing saffron flowers (reduction of 15 million MAD worth of labor) and still produce higher crocus yields, which require harvesting. With harvesting technology unchanged, the higher flower productivity creates a labor bottleneck at harvest time. This leads to large labor reallocations at harvest (85.4 million MAD worth of labor reallocated). Labor reallocations by household group (bottom of table) reaffirm that the technological change in the cultivation season disproportionately impacts labor markets in the harvest season.

These findings shed light on labor-market tensions created by the saffron price boom. High saffron prices stimulate an increase in saffron production and a shift toward high-yielding crocus flower-production technologies. Yet harvesting crocus stigma remains a painstaking, meticulous, labor-intensive task. Further increasing productivity in the cultivation season is likely to increase labor-market pressures (and bid up wages in the harvest season) further.

From a gender perspective, enhancing flower-production technologies creates a serious female-labor bottleneck at harvest time, inducing women to shift their time out of care and leisure activities. Women are able to increase their labor input into care more than in the saffron price increase scenario because of higher labor productivity in saffron, but not enough to compensate fully for the harvest-time decrease. Given the female labor intensities of both care and harvest activities, higher saffron production comes at a potentially large domestic cost.

If new technologies raised productivity in the saffron harvesting and processing stage, harvest-stage bottlenecks could be ameliorated; however, impacts would be felt in both cultivation and harvest activities. We are not aware of technologies on the shelf to increase productivity in saffron harvesting and processing. Simulations of the likely impacts of such an innovation (available on request) show that the major impacts of harvest-stage technological change would be felt in the cultivation period. Higher labor productivity at harvest raises the shadow price of crocus flowers, and this induces households to increase their production of flowers. Improved harvest technology creates a cultivation-labor bottleneck. Improving harvesting technology depresses the harvest-time labor market, as group 1 households reduce their demand for labor and group 3 households keep more of their labor at home.

(c) *Price volatility*

Our simulations show how sensitive labor markets are to saffron price shocks, a direct consequence of the labor-intensive nature of this activity. When variations in saffron prices reach the magnitude observed in the past decade, this sensitivity can amplify the vulnerability of some households. How does volatility in global saffron prices translate into variability in local outcomes? Do general equilibrium adjustments in the local economy buffer households from global price swings?

We used our LEWIE model with Monte Carlo simulations of global price variability to study the consequences of a mean-preserving spread in saffron prices for labor demand, production, incomes, and wages. This entails running two sets of simulation loops, one with a low price variance (S_l^2) and the other with a high price variance (S_h^2). In the first loop, we perform 1000 price-shock simulations just like those analyzed above but with a different price shock each time. Each shock is drawn from a normal saffron price distribution.[11] The distribution of prices is normalized to mean 1.0 and variance 0.05, which corresponds to the variance of the series of world saffron prices before the year 2000 (Figure 2). We record the values of all variables for each simulation and use these to construct a distribution of impacts for each variable in the model.

We then perform a second loop of 1,000 simulations, this time drawing from a normal distribution with variance 0.17 (corresponding to the variance of the price series after 2000) and recording all values for each simulation. This gives us a distribution of impacts for each variable in the model under a scenario of more variable saffron prices. We can compare the percentage change in variance of a given outcome i under the high price variance ($S_{i,h}^2$) and low price variance ($S_{i,l}^2$) scenarios to the percentage change in price variance, that is:

$$\frac{(S_{i,h}^2 - S_{i,l}^2)/S_{i,l}^2}{(S_h^2 - S_l^2/S_i^2)} \quad (9)$$

This reveals the extent to which the variance of the outcome increases with the variance of the saffron price.[12] It can be thought of as the elasticity of the variance of an outcome with respect to the price variance.[13] To our knowledge, this is the first use of a GE model to simulate the impacts of changes in price distributions, as opposed to changes in prices.

Figure 3 compares the outcome-to-price variance elasticities calculated using Eqn. (1) for wage income by gender, as well as for saffron production and real incomes by household. The top bar (hashed) represents the increase in saffron price variance, which we normalized to one. (It is in fact a 220% increase in variance, from 0.053 to 0.172). Bars longer than the hashed one correspond to variables whose variance increases more

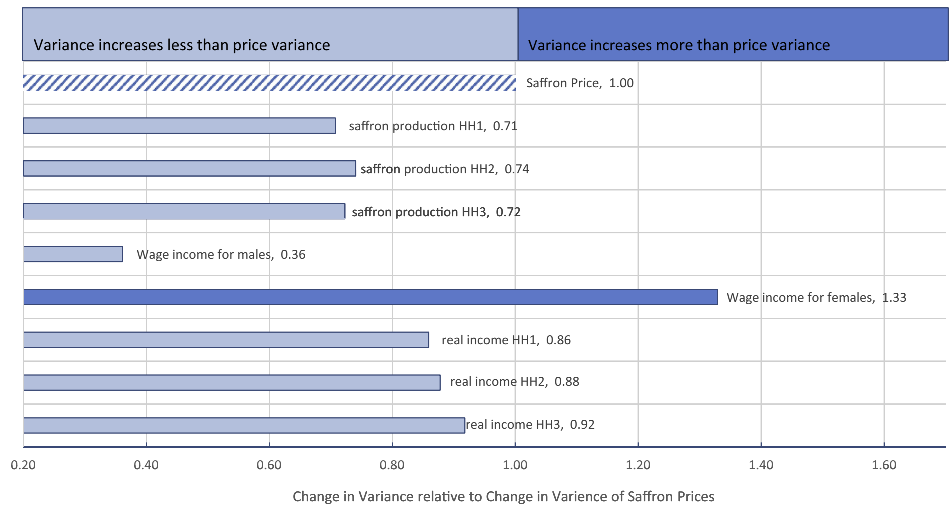

Figure 3. *Effects of increased saffron price variance on variances of wage incomes, production and real income. Source: LEWIE simulations. All variance shock reported relative to the shock in Saffron price variance.*

than the saffron price variance (darker). Bars shorter than the hashed one indicate the opposite, that is, variables for which GE effects buffer households from saffron price volatility.

All bars except female wage income are shorter than the price bar, meaning that GE effects mostly buffer the economy from some of the price variability. In terms of saffron production, about 70% of the price variation translates into output variation. Group 2 households experience the greatest variability.

The variability in production volumes reflects variability in labor inputs, which are similarly buffered from the price variability at around 70% (not in figure). However, while variability in total input demand follows production volumes, only part of that labor is hired, and consequently the demand for hired labor may still be highly variable. The two central bars show a dramatic difference between male and female labor markets and opportunities for earning cash income. The male wage income varies little compared to saffron prices, because males have outside opportunities on the labor market. Females on the other hand have no alternative options for remunerative work: the variability in their wage income is 33% higher than the price variability. The variance in wage income of females is exacerbated compared to saffron price variation.

The three bottom bars show the household income variance elasticities. In real terms, income variability is partially buffered: there is between an 86% and 92% transmission of variability from price to income. This reflects the central role of saffron in this economy. The income transmission of saffron price shocks varies across households. Transmission is greatest for Group 3, which controls few productive resources and is most dependent on wages. Achieving partial income buffering requires sizeable adjustments in production and labor allocations, which are the principal means by which households maintain income in the face of price shocks. This adjustment comes at the cost of unstable labor markets and, especially for females, highly unstable wage income.

5. CONCLUSION AND DISCUSSION

The surge in global saffron prices provided the isolated and resource-constrained region of Taliouine–Taznakht with a unique opportunity for significant growth. Our LEWIE model helps dissect the local response to these price incentives by distinguishing among heterogeneous household responses and explicitly capturing the seasonality and gendered nature of saffron production. In the wake of the price bust, the model also sheds light on how this small export economy responds to exogenous price volatility, and what it means for men, women and different types of rural households in the region.

Our price simulations reveal that an increase in the price of saffron leads to significant reallocation of labor to saffron production, both in harvest and cultivation seasons. It stimulates the labor market, as relatively large producers hire workers from less capital-endowed households. Workers of both genders are put to work, but males are disproportionately affected in the cultivation season while females are disproportionately affected in the harvest season. The saffron boom draws female labor into harvesting activities at the expense of other female-dominated activities, including domestic care.

Technological change leading to increased productivity of saffron flowers also has a profound, gender-differentiated impact on labor markets. The Taliouine–Taznakht region is currently expanding land area in saffron and raising flower yields with investments in drip irrigation, the cost of which is 100% subsidized by the Ministry of Agriculture. Meanwhile, the harvesting technology remains female labor-intensive in hand-picking flowers and processing their stigmas. The adoption of yield-increasing technologies thus creates a sharp increase in the demand for female labor. Our results highlight ways in which seasonal bottlenecks in the production process can shape gender-specific labor-market pressures. The lack of a productivity-enhancing technology in the process of harvesting stigmas out of the saffron flowers means that the production process is limited by harvest (female) labor. The unique opportunity for females to earn wage income in saffron harvesting conflicts with women's responsibilities in the non-monetized economy during the harvest season, although our findings reveal some substitutability of domestic work between seasons.

The saffron price boom did not last: it was followed by an almost symmetric bust. Our simulations suggest that GE effects partially buffer local incomes from global price volatility, as households can adapt their labor requirements. This means that the transmission of price variability to incomes is greatest for the households that depend most heavily on wage earnings. For females, who have limited employment options, this translates to an even greater variability in wage earnings.

A number of questions arise from these gendered simulation results. Increased female labor-market participation in response to higher saffron prices and increases in flower productivity has significant repercussions inside the household. It conflicts with domestic or reproductive activities such as child-rearing. The tension between care and harvesting, given the labor intensity of both, makes the cash-crop supply response lower than it otherwise would be.

The saffron boom may have other repercussions on households and gender roles that are beyond the purview of our model. Wage opportunities for females may affect female school enrollment rates and birth rates (Becker, 1992). Rising cash incomes for females can alter utility weights in intra-household decision making, with possible repercussions on outcomes ranging from household consumption patterns to child nutrition, school enrollment, or family planning. In our price increase simulations, the share of total wage income earned by females increases from 29% to 37%, but this share is extremely volatile in the presence of saffron-price variability. Unpredictable economic opportunities for females may shape intra-household bargaining and interactions along with broader economic and social dynamics differently than predictable and permanent changes.

It is important to realize that such gendered results all stem from the rigidities of the saffron-labor division. If it were common for men to harvest saffron stigmas, the labor market for females would not be so responsive to shocks and price volatility. Likewise, if it were common for men to participate to domestic activities, then the strain on women's time would not be so severe. Thus, if the exclusive reliance on female labor becomes too costly, the regional labor market is likely to adapt by pulling on untapped sources of labor. Men could increase their participation to the harvest activity, or seasonal female laborers from outside the region could begin migrating to the Taliouine–Taznakht saffron harvest—currently an uncommon phenomenon in rural Morocco. The repercussions of such evolutions in local livelihood strategies and rural Moroccan society run deep.

The saffron price-boom only lasted three years. Even though prices have now returned to their historical trend, the peak has taught us (as well as saffron producers) how volatile the price of a global specialty crop can be. Aware of this, the government of Morocco is running ad campaigns to boost national demand for saffron and other local products. Efforts are underway to obtain fair-trade certification as well as Label of Origin certificates, in order to reach the premium market segments – though at this point only 3% of saffron in the region goes through those channels (Aziz and Sadok, 2013). It is likely that the three year saffron boom was sufficiently long to have impacted the economy and society in durable and perhaps irreversible ways. Our model highlights the need to further analyze these evolutions and labor dynamics. While LEWIE cannot tell us how production dynamics have impacted social interactions in Taliouine–Taznakht, it does highlight the spillover effects of saffron prices across activities, genders, and seasons, and it demonstrates the ways in which technical and economic constraints shape impacts of global shocks in local economies. This is a potentially insightful point of departure for exploring and ultimately modeling broader follow-on dynamics in the local economy. For example, new female labor opportunities in the region could emerge endogenously as a response to these gender-differentiated labor market impacts, although local religious and cultural norms may shape opportunities as much as local prices and profits do.

At a general level, our simulations highlight the conundrum in linking smallholders to international markets, particularly in the case of niche markets subject to consumer fads and volatile prices. On one hand, a precipitous rise in saffron prices generated unprecedented incomes for Taliouine–Taznakht households, not only for saffron producers but also for the workers they hire and for the producers of regionally traded goods. It dynamized labor markets, in particular for female workers with few other opportunities for cash income. On the other hand, it left in its wake a tradeoff between poor households' access to high windfall incomes and economic stability. Measures to stabilize saffron prices, in theory, could mitigate adverse effects of global price volatility. Lacking these, local general equilibrium adjustments provide the local economy with a modicum of income insurance; however, it comes at a cost of substantial labor market adjustments, to which female workers and poor wage-earning households are particularly vulnerable.

NOTES

1. The government of Morocco launched a plan to help develop drip irrigation in the area in 2010, when prices were already on the decline (Aboudrare *et al.*, 2014)

2. The heavy reliance on female laborers for the saffron harvest is not a phenomenon limited to Morocco. The saffron harvest has been described as a predominantly female activity in Kashmir in the 1960s (Madan, Kapur, and Gupta, 1966, p. 383) but also in present day Spain (Halvorson, 2008).

3. The term "non-productive" is sometimes used to describe household activities that do not generate incomes. We prefer "domestic" or "reproductive" (i.e., involved with reproducing the household) for reasons that any parent would understand. "Non-monetized," "care economy," and "social reproduction" are other terms used in the literature.

4. The MAD/US$ exchange rate varied from 7.2 to 9.2 during 2007–10.

5. Many CGE models use CES production functions, which have the advantage of allowing the modeler to specify elasticities of substitution, but they do not preserve factor quantities in simulations and they complicate calibration. Thus, when data on elasticities of substitution is unavailable (as in our case), the case for using CES is weak.

6. Using conversion rate of 3.8 currency units per international dollar, from the World Bank Development Indicators.

7. Brooks, Filipski, Jonasson, and Taylor (2010) report estimated factor shares for family labor in two other African countries range from 0.26 to 0.96 in staple activities, 0.29–0.79 for livestock, and 0.24–0.75 in other crop activities. The shares we use fall within these ranges (see Table 5 and data input sheet in Appendix).

8. We use different ratios at cultivation and harvest time because the inequality in females' access to leisure tends to worsen when they enter the labor force (and/or become mothers) (Bruce, 1989). Females of rural low-income households enjoy about half as much (47%) leisure as males in Fontana's gendered SAM of Zambia, where females seldom work out of their homes (Fontana, 2002). They enjoy about a quarter as much (0.26%) leisure as males in a gendered SAM of Bangladesh, where women are heavily engaged in wage work in the textile industry (Fontana and Wobst,

2001). Sensitivity analysis suggests that the results are not particularly affected by these assumptions.

9. Specifically, we use the CONOPT3 solver for non-linear programing, which relies on a quasi-Newton method.

10. We provide a graph in Appendix B showing labor supply over a wide range of price shocks. Results become less symmetric and less linear for larger values of price shocks. This also provides rationale for the price volatility simulations below.

11. 1,000 was chosen as an arbitrarily high number of iterations, large enough that we have no doubts about our variance calculations.

12. Similar results are obtained if we construct the measure using standard deviation, coefficient of variation, index of dispersion, etc.

13. This is not to be confused with the elasticity of an outcome with respect to the price. The two measures are not equal in a non-linear model such as LEWIE.

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APPENDIX 1. MODEL STRUCTURE

(a) *Household model (household subscripts suppressed)*

Utility:

$$U = U(c_i, z_s)$$

for consumption c_i of tradable goods $i = 1, \ldots, I$ and domestic autarkic goods z_s in seasons $s = ph, h$.

Full-income (Y^f) Constraint:

$$\sum_i p_i c_i = Y^f = \Pi + \sum_s \sum_g w_{s,g} T_{s,g}$$

where p_i are market prices, Π is profit from all activities, $w_{s,g}$ is the wage for gender g in season s, and $T_{s,g}$ are time endowments.

Profit:

$$\Pi = \sum_{i \in Tradables} p_i Q_i - \sum_s \sum_i \sum_g w_{s,g} L_{s,i,g}$$

where Q_i is output and $L_{s,i,g}$ are labor inputs.

Saffron production:

$$Q_H = Q_H(Q_F, L_{H,g})$$

Non-saffron (ns) production (includes flowers, domestic goods, and tradables besides saffron):

$$Q_{ns} = Q_{ns}(L_{ns,g}, \bar{K}_{ns})$$

Domestic good constraints:

$$z_s = Q_{z_s}$$

FOCs

Labor, Flowers:

$$p_H \phi \frac{\partial Q_F}{\partial L_{F,g}} = w_{ph,g}$$

Labor, non-flower production (includes saffron):

$$p_{nf} \frac{\partial Q_{nf}}{\partial L_{nf,g}} = w_{s,g}$$

where $w_{s,g}$ is the wage corresponding to the season in which production of good nf occurs (e.g., $w_{h,g}$ for $nf = H$).

Consumption, tradables:

$$U_{c_i} = \lambda p_i$$

Consumption, domestic (autarkic) goods:

$$U_{z_s} = \mu_s$$

Full income constraint (λ):

$$Y^f - \sum_{i \in Tradables} p_i c_i = 0$$

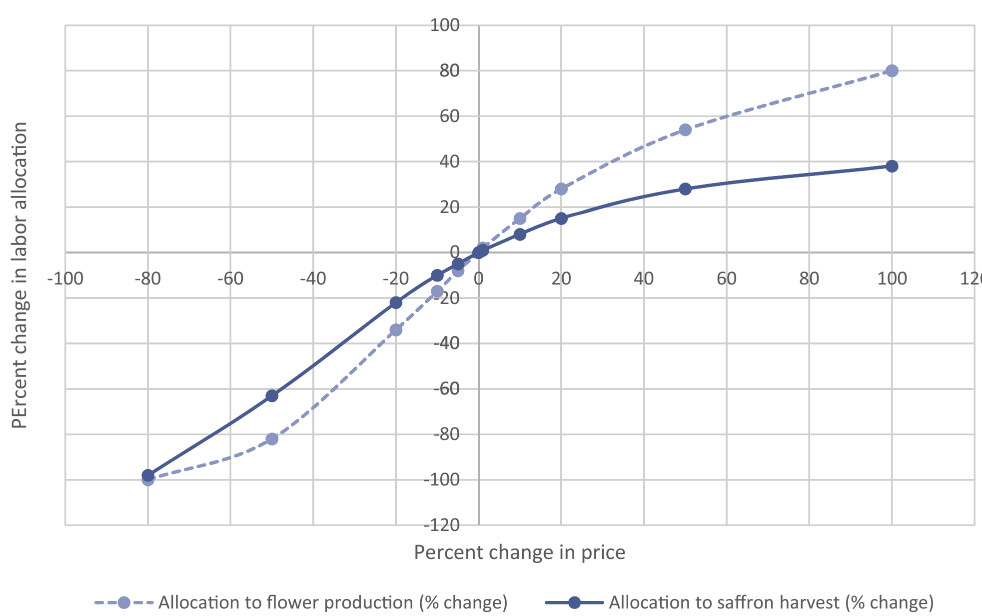

Figure A2. *Change in labor allocations under different price shocks.*

Domestic goods constraints:

$$z_s - Q_{z_s} = 0$$

Lagrangian equation for household optimization problem:

$$\max \ell = U(c_i, z_s) - \lambda(Y^f - \sum_i p_i c_i) - \mu(Q_{z_s} - z_s)$$

(b) *Region market-clearing constraints (adding household subscripts)*

Region-level tradable goods:

$$\sum_{hh} MS_{hh,s,i} = Q_{hh,s,i} - c_{hh,s,i}, \quad p_{s,i} = \bar{p}_{s,i}$$

$i \in \text{Region} - \textit{level tradable goods}$

Domestic goods (autarkic):

$$MS_{hh,s,z} = 0, \quad p_{hh,s,z} = \rho_{hh,s,z}$$

Regional wages:

$$LD_{s,g} = \sum_{hh}\sum_{i} L_{hh,s,i,g} = \overline{LS}_{s,g} = \sum_{hh} \bar{T}_{hh,s,g}$$

APPENDIX 2. SENSITIVITY ANALYSIS

Figure A2

Notes: This sensitivity analysis shows that for small values of price shocks the impacts are close to linear (10% increase has impacts that are roughly double the impacts for a 5% increase), and more or less symmetric around zero (−5% and +5% have roughly opposite impacts). However for larger values this stops being the case as magnitudes are narrowed. As a general rule, general-equilibrium models tend to represent reality better for smaller shocks. *Source*: simulations.

APPENDIX C. SUPPLEMENTARY DATA

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.worlddev.2016.10.018.