Is technology change good for cotton farmers? A local-economy analysis from the Tanzania Lake Zone

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Abstract

Technological change holds the potential to increase crop output as well as incomes of farmers and the communities in which they live. We carry out a local economy-wide impact evaluation of productivity-enhancing technological change amongst small-scale cotton producers in Tanzania’s Lake Zone. Our analysis reveals that demand constraints shift benefits from farmers to downstream processors, while limiting positive spillovers within local economies. Excess cotton gin capacity does the opposite. Interventions to ensure markets for increased output should complement strategies to raise productivity if a project’s goal is to improve welfare in farm households and the communities in which they live.

Keywords: technology change, productivity, local economy, Tanzania, cotton

JEL classification: D24, D58, O33

1. Introduction

Do technological improvements in agriculture reduce poverty and raise incomes for poor farmers? There is evidence that new technologies contribute to poverty reduction in some African and Asian countries (Matsuyama, 1992; Datt and Ravallion, 1998; Irz et al., 2001; Dorward et al., 2004), but also instances in which they fail to benefit poor farmers. The main arguments explaining the latter include an inelastic demand for agricultural output, poor policies and institutions, inadequate infrastructure, high transaction costs, market failures and a lack of state involvement due to market liberalisation.

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This paper examines the constraints that prevent productivity-enhancing technological change from raising welfare in farm households while stimulating income growth in poor rural economies. We contribute to the ongoing debate over the impacts of technological change on rural welfare in two ways. First, we show how to incorporate technological change into a local economy-wide impact evaluation (LEWIE) model to assess the direct and spillover effects of a new agricultural technology. Second, we construct a LEWIE model for Tanzania’s Lake Zone, using econometric analysis of micro-survey data, and use it to simulate the zone-wide impacts of a productivity-increasing technological change in small-scale cotton production under alternative market conditions and supply constraints. Our results demonstrate that local general-equilibrium effects can alter the impacts of production-focused development interventions. They reaffirm the prediction from our theoretical model that market-development measures are likely to be a critical complement to productive interventions for promoting pro-poor growth.

Our paper is organised as follows: Section 2 presents an overview of potential impacts of technological change from a local economy-wide perspective, in the presence of demand and supply side constraints. Section 3 sets up our analytical framework with a simple theoretical model and describes the LEWIE model structure. Section 4 describes the micro-survey data from the Tanzanian Lake Zone, with descriptive statistics on key variables. Section 5 explains how the full impact of productivity-enhancing technological change differs from the direct impacts on cotton farmers. Section 6 describes the construction of the LEWIE model, based on econometric estimation of parameters from original micro-survey data. Section 7 reports the simulation results and Section 8 discusses the results along with robustness checks. The concluding section summarises our findings and their implications for technology and market-development policies.

2. Technological change from a local economy-wide perspective

Technological innovation in staple crops can directly benefit poor households as producers, by increasing their production and incomes, and also as consumers, by lowering food prices. Nevertheless, falling prices due to supply increases ‘can extract from adopting farmers most of the net social gains from technological change to the benefit of rural and urban consumers’ (De Janvry and Sadoulet, 2002: 4). Lower prices of agricultural commodities mitigate welfare gains for small producers of those commodities, transmitting benefits to consumers as well as to producers who demand those commodities as inputs (e.g. agro-processors). Pingali (2007) notes that improved production responses are often met by failed market infrastructure and little or no economic incentive for those adopting mechanisation. While technological improvements have led to expansion in output, productivity gains are often followed by a reduction in local prices (Pingali, 2007; Jayne, Mather and
Mghenyi, 2010). Barrett (2008) emphasises the importance of significant investment by the public sector to ensure institutional and physical infrastructure needed to realise gains from technological advancements and market-based interventions in Sub-Saharan Africa.

Many rural development programmes promote small-scale production of specialty and non-food crops that are not consumed by the crop-producing household. The trade-off between direct benefits to poor farmers as producers and indirect benefits to consumers is more acute in the case of non-food commodities. For households that produce agricultural commodities strictly for sale, the welfare impacts of falling market prices are unambiguously negative. These can mitigate, and in theory even counteract, the positive direct impacts of technological change. Estimated benefits from technological change are sensitive to methods and modelling assumptions, including the nature of markets for the affected commodities (Alston et al., 2009). Within poor countries, transaction costs are likely to limit poor farmers’ access to global markets, and this can lead to a drop in local prices when productivity increases. Missing input and credit markets, lack of extension services and market externalities can further diminish farmers’ welfare gains from new technologies (Chavas, 2011; Dethier and Effenberger, 2012; Lambrecht et al., 2016).

A highly elastic demand for an agricultural product ensures that technology-induced increases in supply gets absorbed downstream while preserving benefits to upstream farmers. One reason why gains from technological improvements have not translated into higher incomes for poor farmers in African countries is due to a highly inelastic demand for agricultural output (Binswanger and Von Braun, 1991; Poulton, Kydd and Dorward, 2006; Pingali, 2007; Jayne, Mather and Mghenyi, 2010). Connecting farmers with new markets or ensuring more elastic demand in existing markets, as well as removing supply side constraints, can be a critical complement to production-based interventions (Pingali, 2007).

Figure 1 gives a broad schematic overview of the possible constraints on poor farmers’ welfare gains from a technological advance that raises crop productivity. We broadly categorise these constraints as demand and supply side. Demand-side constraints limit the market for output gains from technological change, resulting in a negative correlation between output and local farm gate prices. Supply side constraints include adverse conditions in the production process that impede farmers from realising the full potential of productivity-enhancing technological change. In Figure 1, boxes (1)–(5) list potential demand-side constraints and (6)–(8) list supply side constraints.

Inelastic demand for agricultural output (box 1) potentially is one of the most critical constraints limiting poor farmers’ welfare gains from new technologies. Related demand-side constraints include a lack of physical infrastructure to move output off the farm and/or adverse institutions (box 3; see Barrett (2008), Pingali (2007), Dorward et al. (2004) and Binswanger and Von Braun (1991)); the absence of agricultural export markets or high taxation of export crops (box 5) (Collier and Gunning, 1999; Zafar, 2007); and an absence or ineffectiveness of agricultural cooperatives (boxes 4 and 8).
Potential welfare reducing market constraints of technological change in agriculture for the poor

Demand side constraints

- (1) Inelastic demand
- (2) Downstream market structure (monopsony/oligopsony)
- (3) Lack of infrastructure/adverse institutions
- (4) Lack/failure of agricultural cooperatives
- (5) Absence of export markets/high transaction costs

Supply side constraints

- (6) Imperfect or missing input markets
- (7) Liquidity constraints/imperfect or missing credit markets
- (8) Lack/failure of extension services and cooperatives

Fig. 1. Supply and demand-side constraints in agricultural markets.
Cooperatives can play an important role on both the demand and supply side; see Shiferaw, Hellin and Muricho (2011); Wanyama, Develtere and Pollet (2009); Ortmann and King (2007a, b). For crops requiring intermediary processing before being sold as final products, concentrated downstream markets (box 2) could shift benefits of technological change away from crop producers (Sexton et al., 2007; Russo, Goodhue and Sexton, 2011).

This paper focuses on a cotton-producing economy in Tanzania’s Lake Zone, where almost all raw (seed) cotton output is sold to local gins. If productivity gains in seed cotton production put downward pressure on local prices, cotton-producing households lose as producers without gaining as consumers.

The benefits of technological change in cotton production could be transmitted downstream to the cotton ginning sector and outside of the local economy, to gin owners residing in urban areas. Whether or not this happens depends largely on the market structure of the gin industry. Adverse price impacts are not a concern if farmers are price takers in global markets. However, since seed cotton is bulky (and thus expensive) to transport, all cotton farmers, the majority of whom are poor, sell their output at village buying posts set up by local gins. High transportation costs and an absence of direct access to export markets (box 5) for seed cotton characterise our study site.

Supply side constraints could block productivity gains from technological improvements, as illustrated in Figure 1. This would limit impacts on farmers as well as the spillovers they create within local economies. Liquidity constraints and imperfect or missing credit markets (box 7) potentially prevent farmers from realising the full benefits of technological innovations in Tanzania as in most African countries (Little and Watts, 1994; Fafchamps, Udry and Czukas, 1998; Barrett et al., 2005). Liquidity constraints in Africa are often coupled with imperfect or missing input markets (de Janvry, Fafchamps, Sadoulet, 1991; Barrett, Reardon and Webb, 2001). Complementary interventions that expand the market for seed cotton, contract farming, input subsidies and other measures could alleviate some of these constraints and make cotton production more effective at stimulating local economic growth – provided that these interventions target households with the potential to increase production.

Assessing the impacts of technological change in local economies is complicated by interactions among multiple commodity and factor markets and interlinkages among households participating in diverse production activities. Capturing potential local price impacts of technological change requires a local general-equilibrium perspective. However, as Barrett (2008) explains, existing research on technological change in staple production uses either a micro-household or aggregate (national) computable general-equilibrium modelling strategy. A micro-household focus misses general-equilibrium effects of technology change, including price effects. At the other extreme,
country-level computable general-equilibrium models like those of de Janvry and Sadoulet (2002) and others, while useful for analysing the distribution of benefits across aggregate sectors and household groups, are not designed to evaluate local impacts of technological change, for example, in regions targeted by a production intervention.

We fill this lacuna by setting up a theoretical framework and constructing a LEWIE model for a cotton-producing economy in Tanzania’s Lake Zone. The theoretical model demonstrates how market equilibrium in the cotton sector is attained. We use the LEWIE model to simulate the local-economy impacts of cotton productivity-augmenting technological change. The theoretical model shows that, absent an elastic demand for seed cotton by gins, income gains from technological change do not accrue to cotton farmers, but rather, are transmitted downstream to gins via a reduction in farm prices. Excess capacity in the gin sector, on the other hand, can make the demand for seed cotton elastic. This can benefit not only cotton farmers but also households engaged in nontradable food-crop production, retail and services, herding and other activities by way of local general-equilibrium spillovers.

In theory, other mechanisms could ensure an elastic demand for seed cotton output, including state intervention in cotton markets, infrastructure development and cooperatives to market raw cotton. However, a lack of state intervention and liberalisation in the cotton sector, along with failures of cooperatives in Tanzania, have led to the emergence of private ginning companies as the sole buyers of seed cotton. Following liberalisation of the cotton sector beginning in 1992–1993, the Tanzanian government disbanded monopolies of regional cooperative unions and the cotton board to allow private agents to buy seed cotton (Ngaruko and Mbilinyi, 2014a). Cooperative unions were unable to obtain working capital to run their ginneries (Ngaruko and Mbilinyi, 2014b). In an effort to avert sharp price drops, the regional government ensures that a predetermined minimum price is maintained throughout the cotton buying season (mid-June through late September). This price is negotiated with cotton ginners.

Our simulations corroborate the theory that, without excess capacity in the ginning sector, local markets would transmit most of the benefits away from poor cotton farmers to the gins. While this would create some positive feedback through local employment benefitting poor households, it would mostly benefit actors outside the local economy. We contrast these findings with a scenario in which the gin sector has excess capacity, as currently appears to be the case in Tanzania. This excess capacity results in a highly (almost perfectly) elastic demand for seed cotton. Ginning companies face constant pressure to supply pre-committed amounts of cotton lint to their domestic and international customers, which often results in ginners competing to procure seed cotton at even higher-than-market prices.

2 For example, see Sarris (2001) and Winters et al. (1998).
3 Tanzania Cotton Board (TCB) ginneries data for 2015 indicates that 36 per cent of ginners are dormant, and of those active, they are running at 79 per cent capacity on average (Price Waterhouse Coopers, 2011).
While the Tanzanian cotton sector has been evaluated in the past (Poulton and Maro, 2009; Mwangulumba and Kalidushi, 2012), important knowledge gaps remain. First, there has been scarcely any rigorous evaluation of the impact on poor rural households. Second, evaluations of the impacts of higher yields ignore spillovers within the rural economy. Findings from other research suggest that spillovers from technological change can create significant indirect impacts in local economies, including on non-farm households (Taylor and Filipski, 2014). It is possible that the impacts of cotton production on local economies are considerably larger than what is revealed by evaluations focusing only on cotton producers.

This paper adds to the literature on agricultural markets by emphasising the importance of ensuring an elastic demand for an agricultural commodity following technological improvements that raise productivity. We perform sensitivity tests to check the robustness of our results and uncover policy measures that could complement technological improvements by mitigating negative price effects in the absence of an elastic demand for cash-crop output.

3. Analytical framework

We first set up a theoretical model to demonstrate how equilibrium is achieved in the seed cotton market. Then we outline details of the local economy model, which links heterogeneous household groups with the diverse activities in which they engage. In the theoretical setup, an excess capacity in the gin sector\(^4\) ensures that prices remain unchanged, as unutilised gins are brought on line to absorb any excess supply. In other words, individual ginneries do not exercise any market power in seed cotton procurement\(^5,6\). Without excess capacity in cotton ginning companies, the demand for seed cotton by gins is highly inelastic, inasmuch as there are no alternatives like cooperatives and an efficient marketing infrastructure to absorb the expansion in production.

3.1. Theoretical model

Cotton farmers produce seed cotton, which is procured by gins at a competitive price while there is excess capacity in the gin sector. Upon reaching full gin capacity, the seed cotton price adjusts to equilibrate the local market.

A representative cotton gin uses a composite variable input along with seed cotton to produce cotton lint. The composite variable \(k\) exhibits diminishing marginal returns, but gins use seed cotton in fixed proportions to produce

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\(^4\) The ginning sector in Tanzania is characterised by excess capacity for both private firms and cooperatives. Poulton and Maro (2009) note that only 63 per cent of the gins owned by private companies were operational in 2002.

\(^5\) Baffes (2004) notes that TCB ensures competitive prices due to excess ginning capacity.

\(^6\) In Section 7, we discuss how market power in the cotton ginning sector could have different welfare implications for cotton farmers.
cotton lint. The demand function of a representative gin is \( q_L^* = q_L(p_L, p_C, r) \), which is obtained by maximising profit \( \pi_L = (p_L - p_C)f(k) - rk \), where \( p_L \) is the output price of cotton lint, \( p_C \) is the seed cotton price, \( r \) is composite input price and \( f(k) \) is a standard neoclassical production function with diminishing marginal returns. The partial derivatives of the demand function exhibit the usual signs.

The total production of cotton lint by the ginning sector is given by \( Q_L^* = Mq_L^* \), where \( M \) is the number of operating gins in the industry. Owing to excess capacity in the cotton lint producing sector, \( M \) can be changed costlessly in the short run. If there is a shortage of seed cotton supply, some of the gins could be left unutilised without changing prices due to Tanzania Cotton Board (TCB) intervention; similarly, there are some excess gins that could be made operational to accommodate an increased supply of seed cotton until full gin capacity is reached.

The demand for seed cotton derives from the Leontief relationship between cotton lint and seed cotton. Without further loss of generality, we can measure units so that the Leontief coefficient converting seed to lint cotton is 1.0 and thus \( Q_C = Q_L \): one unit of seed cotton is used with the composite input to produce one unit of cotton lint. In our setup, we assume that the maximum capacity of the gin sector is fixed at \( \bar{M} \) in the short run. Once this capacity is reached, the seed price adjusts to determine the equilibrium quantity of seed cotton.

The seed cotton-producing sector is characterised by \( N \) identical cotton producers with a constant returns to scale production technology. A representative cotton producer’s supply function is \( q_C^* = q_C(p_C, p_X, T; A) \), where \( p_C \) and \( p_X \) are per unit prices of seed cotton and the variable input \( X \), respectively. \( T \) is an input that is fixed at \( \bar{T} \) in the short run, and \( A \) represents a technological shift parameter. The supply function, \( q_C \), is assumed to have standard first derivatives with respect to its arguments. The optimal supply is increasing in output price, the shift parameter and the fixed input, but it decreases with input prices. The total quantity supplied by cotton producers is the industry supply of seed cotton: \( Q_C^* = Nq_C^* \).

Equilibrium in the two sectors is determined by the following relationship, which equates the supply and demand of seed cotton:

\[
Nq_C(p_C, p_X, \bar{T}; A) = Q^* = Mq_L(p_L, p_C, r)
\]  

(1)

Gin capacity \( M \) adjusts to absorb seed cotton output until the maximum gin capacity, \( \bar{M} \), is reached; that is, the seed cotton demand is perfectly elastic up to \( \bar{M} \). Once the gin sector is at full capacity, the seed cotton price adjusts to achieve equilibrium. This can be shown by using the implicit function theorem. We can rewrite (1) as \( F(p_C, A, M) = Nq_C(p_C, p_X, \bar{T}; A) - Mq_L(p_L, p_C, r) = 0 \), where \( F(p_C, A, M) \) is in the implicit form. Given the assumptions on the supply and demand functions, we have
This implies that, ceteris paribus, following a technological improvement in seed cotton production, quantity supplied increases, leading to expansion in the ginning sector as previously unutilised gins come on line. However, once full capacity of the gins is attained, the price received by cotton producers decreases, i.e.

\[
\frac{\partial M}{\partial A} > 0 \quad \text{and} \quad \frac{\partial p_C}{\partial A} = 0 \quad \text{if } M < \bar{M} \tag{4}
\]

\[
\frac{\partial M}{\partial A} = 0 \quad \text{and} \quad \frac{\partial p_C}{\partial A} < 0 \quad \text{if } M \geq \bar{M} \tag{5}
\]

### 3.2. Modelling local economy impacts

Local general-equilibrium effects cannot be evaluated with structural models at the micro (i.e. agricultural household) or aggregate (country CGE) level. Nor is it practical to evaluate them with a reduced-form experiment, given the challenges of randomising cotton-technology treatments at a sufficient number of sites to precisely estimate spillovers. Understanding spillovers requires a LEWIE approach that captures the impacts of cotton-production interventions in local markets.

Technological change creates direct and indirect (spillover) impacts. Producers benefit directly from increases in productivity, which might raise their incomes and consumption possibilities. The spillovers from technology change operate principally through prices. We expect local market linkages to be important, because cotton production injects a considerable amount of cash into local economies, households tend to spend most of their income close to home, and many of the goods and services households demand are supplied within the local economy.

Because of impacts on input markets and consumption demand, an additional shilling from cotton production could generate a real-income multiplier greater than one shilling in cotton-growing regions. Local demand and supply side constraints, on the other hand, may limit the multiplier effects of technological change on production and incomes. In our case study, cotton farmers are directly affected by any policy or project aimed at cotton production.

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7 In Section 2 of Supplementary materials, we provide an example for the theoretical model using explicit functional forms.
Thus, they are analogous to the ‘eligible’ households in an experimental design. We also include non-cotton-producing agricultural households and other households that are not primarily agricultural. These households, by definition, are ‘ineligible’ for the cotton-productivity ‘treatment’.

3.2.1. Households, activities and model calibration

To construct the Tanzania cotton LEWIE model, micro-survey data were used to econometrically parameterise a series of agricultural household models (Singh, Squire and Strauss, 1986; Taylor and Adelman, 2003). These were nested within a general-equilibrium model of the Lake Zone, following the methodology presented in Taylor and Filipski (2014). In this model, prices transmit impacts from the direct beneficiaries (in our case, cotton farmers) to others inside and outside of the Lake Zone.

The agricultural household models describe each group’s productive activities, income sources and expenditure patterns. Household groups participate in multiple activities, including cotton production, cultivation of other crops, livestock production and a wide diversity of businesses. The businesses are classified as retail, service, ginning, or other non-agricultural (including local food processors). The gin sector is comprised of ginning companies that procure seed cotton from farmers and process it into cotton lint.\(^8\) Thus, as in our simplified theoretical model, the output of cotton production is an intermediate input into ginning.

All activities use factors (e.g. hired labour, family labour, land, capital), which are sourced inside the zone (often from the household, itself), as well as intermediate inputs that (with the exception of seed cotton) are likely to be sourced outside the zone (e.g. purchased inputs for agriculture and merchandise for local shops). The transformation of factors into outputs is described by activity-specific Cobb-Douglas production functions.

Households also supply wage labour to local production activities, and they purchase goods and services locally or outside the Lake Zone. Household consumption demands are modelled as household-specific linear expenditure systems, implying Stone-Geary utility. Trade in goods, services and factors link household groups within the Lake Zone as well as to the rest of Tanzania. Weaker interactions with outside markets generally imply fewer leakages, making it more likely to detect impacts within the local economy.

The survey data provide initial values for all variables in the model. The initial values of each variable in the model, together with the model parameters and standard errors, were organised into a data input spreadsheet designed to interface with GAMS, where the LEWIE model resides. The LEWIE model is available in the Supplementary Material as a GAMS text file.

\(^8\) The Tanzanian ginning sector comprises over 50 firms, of which approximately 30 operate in a typical season. They are located throughout the Lake Zone, with the largest concentrations in Bariadi and Shinyanga districts.
3.2.2. Model closure

For each good and factor, closure rules determine where markets clear and prices or wages are determined. A challenge in general-equilibrium analysis is that we usually do not know exactly where prices are determined. In real life, changes in prices outside of an economy may be transmitted into the economy. Given the size of the cotton industry in Tanzania, there is little reason for cotton improvements to affect prices of cotton lint outside the Lake Zone.9

Even if the region is a price taker in the ginned cotton market, this does not imply that it is a price taker in seed cotton. Transaction costs limit poor farmers’ access to markets outside the region. Thus, the interaction of local supply and gin demand determines the seed cotton price, and unless demand is elastic, increases in cotton productivity put downward pressure on the local cotton price. In our base model without excess gin capacity, an endogenous seed cotton price links cotton producers to gins. A lower seed cotton price stimulates gins’ intermediate demand for cotton. This mitigates the decrease in seed cotton price, while transmitting benefits of technological change from farmer to gin. The net impact on the seed cotton price is not known ex-ante; we must simulate it. Once we carry out the technology experiment using the base model, we modify the model to reflect the current Tanzanian context of excess gin capacity.

We assume that household capital and land endowments are fixed and neither capital nor land can be reallocated between activities. These are reasonable assumptions, particularly in the short run, given our choice of activity aggregation: Crop cultivation implements are of little use in livestock or service activities, especially when markets are thin.10 Thus, the rental rates on capital and land are household-specific shadow values.

Labour is tradable within the Lake Zone, but in light of high transaction costs, the zone cannot freely ‘import’ wage workers from other parts of the country; thus, wages are endogenous. Impacts of labour-demand shocks may be muted if there is an elastic supply of labour, as is likely to be the case in the Lake Zone where un- and under-employment rates are high. Labour supply elasticities cannot be estimated with available data. We assume a nearly perfectly elastic labour supply (=100).11

All other goods in the model are assumed to be tradable, with prices determined outside the Lake Zone. Thus, the model distinguishes among three levels of market closure: the household, the regional market and outside the

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9 Tanzania is ranked 21st in cotton lint production among cotton-producing countries. See https://icac.generation10.net/, Accessed 6 September 2017.
10 This also means that agricultural tradables (which we aggregated with all other tradables) do not compete with agricultural non-tradables for land and capital, which we believe is an acceptable simplification. Tradables represent a small fraction of total agricultural output and tend to be different crops (e.g. fruit trees). Alternatives offer little appeal. Perfectly re-allocable land would overinflate supply responses. Imperfectly elastic land reallocation a la Jonasson et al. (2014) would have required for us to guess at elasticities of transformation, for little gain.
11 This reflects excess labour supply in the Lake Zone and is similar to the way labour is treated in SAM multiplier models. Excess labour supply can be expected to lower inflationary pressures by limiting wage increases. It does not remove inflationary pressures, however, because land and capital constraints continue to limit the local supply response.
region. Monte Carlo simulations (Taylor and Filipski, 2014) and sensitivity analyses were used to test the sensitivity of our simulation results to labour supply elasticities as well as errors in parameter estimation and alternative closure assumptions.

The sets, accounts, variables, parameters, equation definitions and equations in the model are summarised in Tables S5–S10 in the supplementary material. The model equations include production and input demand functions; expenditure functions for each household group; and local market-clearing conditions, which determine prices for non-tradables or, for tradables, net trade with the rest of the country at exogenous prices.

4. Data
As many as half a million farmers grow cotton, mostly marginal producers concentrated in some of the poorest and least fertile regions of Tanzania’s Lake Zone.12 Besides poor soil quality, these farmers suffer from a variety of constraints that prevent them from achieving the income gains of their USA, Asian, Australian or even West African counterparts. Some of these challenges include low productivity in cotton production, low quality cotton, and low and volatile cotton prices (Mwangulumba and Kalidushi, 2012). Tanzania’s average cotton yields are among the lowest in the world. There are large year-on-year fluctuations in the world price of cotton lint. The lack of a transparent pricing mechanism subjects prices of cotton lint to political influences (Ngaruko and Mbilinyi, 2014a).

A detailed household survey was carried out to provide the data needed to construct the LEWIE model for the Lake Zone of Tanzania. The data were collected through a survey of cotton and non-cotton-producing farmers in September and October of 2014.13 A total of 20 districts were selected from the six regions where cotton traditionally has been grown. After these districts were chosen, three villages were randomly selected from each district, and respondents were chosen randomly within each village. The final dataset has a total of 60 villages and 1,534 households. Our focus is on cotton production, but non-cotton-producing households and businesses were also surveyed. We classified households as cotton growers if their main source of income and primary cultivated crop were both cotton.

4.1. Sample
The sample consists of 839 cotton-producing households, 435 non-cotton-producing households, 111 businesses and 129 labourers (Table 1). Detailed

12 Defined for the purposes of this study as the seven regions comprising the Lake Zone administratively (Geita, Kagera, Kigoma, Mara, Mwanza, Shinyanga and Simiyu) in addition to two neighbouring cotton-growing regions in the Central Zone administratively; Singida and Tabora.
13 The survey was conducted by KIT as part of the Tanzania Cotton and Textiles Development Program (CTDP) Economic Impact Study, supported by the TGT in the six cotton-growing regions in the Lake Zone of Tanzania.
income data from the survey make it possible to classify households as below
the poverty line (BPL) or above the poverty line (APL), using the 2011–2012
Tanzanian government-established national poverty line. The reason for this clas-
sification is to demonstrate the heterogeneous impacts of cotton technological
change on households at different income levels within each group. We also
deﬁned a business/other household group whose main income source was from
non-agricultural activities like retail, services and non-agricultural production.14
Finally, we identiﬁed a (nearly) landless labour group (land ownership less than
1 acre).15 The household groups in our model are thus: Cotton producers BPL,
Cotton producers APL, Non-cotton producers BPL, Non-cotton producers APL,
Business/Others, Labourers.

Overall, 56 per cent of all households are below the national basic needs
poverty line; 57 per cent of the cotton producers, 55 per cent of non-cotton-
producing households, 41 per cent of the business group and 68 per cent of
the labourers are poor. A majority of the business/other households are APL,
while most of the labourer households are BPL. We used an asset-based
index as a robustness check on the poverty classiﬁcation.16 Based on the
asset index and income measure, our household classiﬁcation appears to be
meaningful both in terms of income and asset poverty levels.

4.2. Household characteristics

Detailed data were gathered on all production activities carried out by each
household, including the cultivation of cotton and other crops, livestock and
any non-farm businesses in which the household was engaged. For each activ-
ity, information was collected on production and its uses as well as on all
inputs, family or purchased, variable or ﬁxed. The survey also gathered infor-
mation on other income activities and sources, including wage employment by

| Group      | Cotton producers | Non-cotton producers | Business/others | Labourers | Total |
|------------|------------------|----------------------|-----------------|-----------|-------|
| BPL        | 478 (57%)        | 241 (55%)            |                 |           | 852 (56%) |
| APL        | 381 (43%)        | 194 (45%)            |                 |           | 682 (44%) |
| Total      | 839              | 435                  | 111 (41% BPL)   | 129 (68% BPL) | 1,534 |

Note: Figures in parentheses are percentages of total.

14 Retail includes village or town stores, which obtain much of their merchandise from whole-
salers outside the local economy. Services include a variety of activities ranging from haircuts
to construction, maintenance services and transportation. Local production includes a variety of
non-agricultural, non-service activities, including home produced crafts, ﬁrewood, food process-
ing, home breweries and workshops.

15 We ﬁnd, based on observation, that most of the households with less than 1 acre of landholding
are poor agricultural labourers, whom we deﬁne as the labour group.

16 The methodology for asset index construction and a sensitivity analysis appears in Table S1 of
the Supplementary Materials.
each household member, public and private transfers, and remittances, as well as household expenditures on food and non-food items. For all purchases and sales, the place at which the transaction took place was recorded to locate transactions inside or outside of the Lake Zone.  

Household economies in the Lake Zone, like in most rural areas, are diversified in terms of economic participation, with heterogeneous human capital levels. The business/others group and labourer households produce limited amounts of cotton. Non-cotton-farming households are primarily focused on other agricultural crops and livestock activities. Some agricultural and labourer households also own businesses.

Cotton BPL households have the largest average family size (Table 2). They have less land than APL households (11.4 compared to 15.2 acres) and also cultivate less. The labourer group has almost no land on average; however, households in this group cultivate an average of 3.7 acres. This reflects an active land leasing market. We do not find any significant differences in land cultivation between non-cotton-producing BPL and APL households. Average cotton production is significantly different for APL and BPL cotton-producing households. There is no significant difference in cotton production for business and labourer households.

5. Transmission mechanism and spillovers

The simulation model captures the full impact of cotton production on the local economy, as local input and goods markets create income linkages that eventually converge to local income multipliers. The impact of increased demand on production and on the local income multiplier depends on the supply response to prices. The more elastic the supply response, the more productivity-increasing technological changes will tend to create positive spillovers in the economy. The more inelastic, the more they will raise prices instead of stimulating production. If the production supply response is very inelastic (that is, constraints limit producers’ ability to raise output), technology change in the cotton sector could have inflationary impacts in the sectors that produce non-tradables. Higher output prices benefit producers but harm consumers. If wages increase, employed workers will benefit, but producers will be adversely affected. The total impact of technological improvement in cotton on the local economy depends on the interplay of these price and output effects.

Figure 2 illustrates the transmission of impacts through the Lake Zone economy, which depend on the structure of the household models as well as interactions among households within the LEWIE model. Cotton-producing households demand labour and other inputs as well as consumption goods and services from other households in the Lake Zone. Production and

17 A detailed description of these and other (including socio-demographic) data gathered by the survey is available in Zaal, Bymolt and Tyszler (2014).
18 Table S2 in the supplementary section provides educational attainments of household heads of different household groups.
| Household group characteristics | Cotton producers | Non-cotton producers | Business/others | Labourers |
|-------------------------------|------------------|----------------------|-----------------|-----------|
|                               | BPL  | APL              | BPL  | APL       | 385  | 129                       |
| Household size                | 9.2  | 7.9 (0.22)       | 8.2  | 7.4 (0.26) | 7.4  | 5.7 (0.25)                |
| Total landholding (acre)      | 11.4 | 15.2 (1.29)      | 10.8 | 11.0 (0.75)| 10.4 | 0.2 (0.04)                |
| Land cultivated in last season (acre) | 7.8  | 10.4 (0.4)       | 7.4  | 7.1 (0.34) | 7.1  | 3.7 (0.26)                |
| Total cotton output (thousand kg) | 498.4 (22.1) | 1014.8 (53.6) | –   | 287.3 (74.2)| 220.8| 28.1                     |
| Total                         | 474  | 385              | 240  | 111       | 129  |                          |

Note: Values in parentheses are standard deviations of means for each variable.
consumption linkages transmit impacts of cotton production from cotton to non-cotton-producing households (and back again) as illustrated in the figure.

The cotton sector shock gets transmitted directly to the cotton-producing households and to a smaller extent to non-cotton, business and labourer households (1). Production and consumption linkages transmit impacts to other cotton producing as well as non-cotton BPL and APL households (2). Non-Cotton BPL and APL households then transmit impacts through production and consumption linkages to the other household groups (3). In subsequent rounds, all households transmit impacts to each other; however, leakages in the form of expenditures outside the Lake Zone reduce the local impacts in subsequent cycles (4).

6. Econometric results

Econometric estimates using the microdata provide initial values for all parameters in the LEWIE model. These include parameters of production functions for each agricultural and non-agricultural activity and household expenditure functions. Where production technologies differ across household groups, the production function estimates are both activity and household specific. Gin profit functions were estimated with data from gins.

6.1. Production linkages

The households participate in agricultural and non-agricultural production activities, classified as cotton, crops other than cotton, livestock and
businesses. We use the following Cobb-Douglas production function to describe technology in the different productive activities:

\[
\ln(\text{output}_i) = \beta_0 + \beta_1 \ln(\text{land}_i) + \beta_2 \ln(\text{household labour}_i) + \beta_3 \ln(\text{hired labour}_i) + \beta_4 \ln(\text{purchased inputs}_i) + \beta_5 \ln(\text{capital stock}_i) + u_i
\]

Cotton producers purchase inputs from households and businesses inside and outside of the local economy. Most labour in cotton production originates from either the cotton-producing households themselves or is hired locally. Local labour markets transmit impacts of changes in cotton production to other households. To calculate the total value of cotton production and the inputs used for each cotton-farming household, we use prices at the village level with the quantities reported by farmers. The production function estimates enter the LEWIE model as value-added shares. The estimates reported in Table 3 assume constant returns to scale (unconstrained Cobb-Douglas estimations yielded similar results).

The household-specific Cobb-Douglas production function parameters in Table 3 are the elasticities of total value-added with respect to labour and other inputs in each production activity. They also represent the share of each factor in activity value-added. Four out of the six household groups participate in cotton production to some degree. The first four columns of Table 3 give cotton production estimates by the different household groups. Columns 5–8 present estimates for activities carried out by the non-cotton farmers, which include other crops such as rice, maize, cassava, etc., as well as livestock production.

We use output values to pool the other crops into non-cotton crop production (columns 5–6). Similar to the cotton output calculation, total production and input values for other non-cotton crops were measured using prices at the village level together with the respective quantities of each crop as reported by farmers. Livestock graze on open lands rather than designated pastures, but the CRS assumption for livestock production made it possible to derive the exponent on land as a residual. Production function estimates for retail and service businesses appear in Columns 9 and 10, respectively.

Cotton BPL and APL households pay out 0.08 and 0.05 TSH to hired labour per TSH of value-added in cotton production, respectively. The hired labour shares for business and labourer households engaged in cotton production are 0.18 and 0.07 TSH, respectively. High hired labour elasticities increase the income of local households that supply labour to cotton production. Purchased inputs from the rest of the world represent 0.1 and 0.18 TSH for each 1 TSH of value-added generated by cotton in BPL and APL cotton households, respectively. This reflects the low purchased-input intensity of BPL farmers. Family value-added shares are 0.14 TSH (BPL) and 0.07 TSH (APL).

Capital shares in APL and BPL cotton households are 0.01 and 0.007 TSH, and returns to land are 0.68 TSH and 0.69 TSH, respectively. This is in contrast to business households, which receive a higher return to capital, 0.09 TSH, and lower return to land, 0.53 TSH. Nearly one-third of value-added in
Table 3. Production function estimates by activity and household group

| Dependent variable | Log of total value of cotton output (in TSH) | Log of total value of output of all other crops (in TSH) | Log of total value of output of all livestock units (in TSH) | Log of total sales from retail or services (in TSH) |
|--------------------|---------------------------------------------|----------------------------------------------------------|-------------------------------------------------------------|-----------------------------------------------|
| Log of land        | 0.676*** (0.0816)                           | 0.641*** (0.104)                                          | –                                                           | –                                             |
|                    | log of household labour                     |                                                          |                                                              |                                               |
|                    | 0.140*** (0.0490)                           | 0.194** (0.0920)                                          | 0.0515 (0.0338)                                             | 0.0457** (0.0191)                             |
|                    | log of hired labour                         |                                                          |                                                              |                                               |
|                    | 0.0798*** (0.0271)                          | 0.130*** (0.0367)                                         | 0.0751** (0.0323)                                           | 0.0760** (0.0316)                             |
|                    | log of purchased inputs                     |                                                          |                                                              |                                               |
|                    | 0.0964*** (0.0367)                          | 0.0480*** (0.0120)                                        | 0.0317** (0.0127)                                           | 0.878*** (0.0259)                             |
|                    | log of capital stock                        |                                                          |                                                              |                                               |
|                    | 0.00756 (0.0108)                            | –10.0127 (0.0277)                                         | 0.790*** (0.0512)                                           | –                                             |
| Constant           | 10.33*** (0.407)                            | 10.41*** (0.378)                                          | 2.325*** (0.693)                                            | 1.950*** (0.404)                              |

N = 453 372 42 64 238 194 131 147 190 70

R² = 0.850 0.762

F = 274.8 2,088.9 92.93 190.5 149.6 310.3 117.2 102.7 13.51 336.6

Standard errors in parentheses are clustered at village level. R-squared are not reported for constrained regressions. The CRS production function estimates are obtained by constraining the factor elasticities to sum to one.

*p < 0.10, **p < 0.05, ***p < 0.010.
non-cotton crop activities by both BPL and APL farmers goes to local family and hired labour. The largest value-added shares are for land in crop production and capital in livestock and retail production. In livestock production, capital includes the value of the herd. Land and herd value-added flows into the households that own land and livestock. The capital value-added from retail accrues to the households that own local shops and is not estimated here. Purchased inputs have the largest value-added share in both retail and service production.

The final production linkage is from the ginning sector, which constitutes part of the value-added chain in the production of cotton oil, textiles and other cotton-based products.19 This sector benefits from improvements in the output of cotton-producing households, expanding if additional seed cotton is produced. Gins’ impact on the local economy operates through the hired labour market, purchases from local retail, service demand and some reinvestment of profits, as well as gins’ purchases of seed cotton.

Based on our survey of gins, we estimate that 48 per cent of gin profits leave the Lake Zone.20 The rest accrue to Lake Zone households. Drawing on data from a proprietary report by the TCB and TGT’s joint study and a survey of gins done by the Price Waterhouse Cooper (2011),21 we use the production of cotton lint, cotton seed oil and cotton seed cakes from seed cotton to estimate the ginneries’ profit functions.

6.2. Consumption linkages

Increases in cotton production result in increased net income for cotton-producing households as well as for others that supply inputs to them. These households spend most of this income within the Lake Zone economy. The way in which households spend their income determines how consumption linkages transmit impacts. We used data from the household survey to estimate marginal budget shares for food and other goods and services. The shares, reported in Table 4, reveal how each shilling increase in income affects households’ demand for different goods and services.22

For every 1 TSH increase in income, cotton producers (cotton households and some business and labourer households) spend over 0.5 TSH on food and other retail purchases (calculated by summing crop, livestock and retail budget shares). Some food comes from local farmers and some comes from

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19 We only focus on cotton lint. Other sectors could not be modelled due to lack of adequate data.
20 48 per cent of gin profits are assumed to leave the Lake Zone economy, since 37 per cent of total profits are from gins with their headquarters located in Dar es Salaam or elsewhere outside the Lake Zone. In addition, 18 per cent of other profits from the remaining gins, amounting to 11 per cent of total profits, are based on the percentage of business households outside purchases (PWC gin survey, 2011).
21 This report assessed the efficiency of operations, profitability and employment to estimate gins’ profits.
22 These are simplified tables used for demonstration of the linkages in the economy. For the more complex derivation of income from production and how these budget shares are used in the LEWIE models, see Taylor and Filipski (2014: 65–67).
Table 4. Expenditure function estimations giving budget shares by group for 1 TSH increase in income

| Dependent variable | Cotton BPL | Cotton APL | Non-cotton APL | Non-cotton BPL | Business/others | Labourers |
|--------------------|------------|------------|----------------|----------------|-----------------|-----------|
| Food/crop          | 0.157***   | 0.245***   | 0.267***       | 0.270***       | 0.167***        | 0.117***  |
|                    | (0.0144)   | (0.0168)   | (0.0210)       | (0.0237)       | (0.0304)        | (0.0259)  |
| Livestock          | 0.0687***  | 0.0839***  | 0.0628***      | 0.0717***      | 0.0421***       | 0.0199*** |
|                    | (0.00694)  | (0.00980)  | (0.00727)      | (0.0112)       | (0.0104)        | (0.00646) |
| Retail             | 0.342***   | 0.264***   | 0.246***       | 0.259***       | 0.337***        | 0.372***  |
|                    | (0.0169)   | (0.0191)   | (0.0197)       | (0.0259)       | (0.0346)        | (0.0356)  |
| Services           | 0.145***   | 0.128***   | 0.116***       | 0.147***       | 0.124***        | 0.138***  |
|                    | (0.00855)  | (0.0129)   | (0.0104)       | (0.0213)       | (0.0215)        | (0.0235)  |
| Production         | 0.0313***  | 0.0147***  | 0.0197***      | 0.0116***      | 0.0318***       | 0.0267*** |
|                    | (0.00402)  | (0.00386)  | (0.00380)      | (0.00269)      | (0.00754)       | (0.00540) |
| Transfer out       | 0.00847*** | 0.00876*** | 0.00860***     | 0.00313***     | 0.00611***      | 0.00324***|
|                    | (0.00179)  | (0.00176)  | (0.00170)      | (0.00175)      | (0.00144)       | (0.00116) |
| Transfer in        | 0.00137*** | 0.00185*** | 0.000453       | 0.00263***     | 0.00421***      | 0.00257***|
|                    | (0.000409) | (0.000773) | (0.000561)     | (0.00151)      | (0.00163)       | (0.000995)|
| Formal savings     | 0.00129    | 0.000980   | 0.000668       | −0.00100       | 0.00612         | −0.00456 |
|                    | (0.00150)  | (0.00221)  | (0.00128)      | (0.00239)      | (0.00468)       | (0.00658) |
| Informal savings   | 0.0494***  | 0.0114**   | 0.00153        | 0.00382        | 0.0348*         | 0.0865*** |
|                    | (0.00794)  | (0.00488)  | (0.00118)      | (0.00669)      | (0.0183)        | (0.0219)  |

N: 463 359 234 175 101 123

Standard errors in parentheses.

Seemingly unrelated regressions for each group with total expenditure as the independent variable while the dependent variable is in the first column of Table 4. The parameter estimates are on total expenditure with estimates on constant not reported in the table. The estimates are budget shares for 1 TSH increase in expenditure for each household group.

*p < 0.10, **p < 0.05, ***p < 0.010.
traders and retail shops. It matters where households purchase their food; buying from local households keeps this income circulating within the local economy (increasing the multiplier effect), while buying from traders and retail shops largely results in leakages to outside markets from which sellers source their goods. Services like haircuts, carpentry and entertainment are mostly provided locally. Cotton producers also spend money on locally produced goods such as firewood and local crafts. They save a portion of their income in informal and formal financial institutions. Households spend smaller shares of income directly in markets outside the Lake Zone economy. APL households spend more of an increase in income in outside markets than BPL households. Local purchases put shillings into the hands of local business owners, livestock producers and farmers, many of whom do not produce cotton.

By supplying inputs and consumption goods to cotton households, incomes of non-cotton farmer households, business households and labourer households increase, and so does their demand for goods and services. Multiple rounds of diminishing demand increases can reinforce the expansionary effect of cotton production on local economies. They also can have positive feedback effects on cotton-household income, given that cotton-producing households engage in a diversity of non-cotton activities, as well.

7. LEWIE simulation results

The LEWIE model was used to simulate the impacts of a factor-neutral productivity-increasing technological change in cotton production on the Lake Zone economy. The simulations emulate an experiment in which the zone is ‘treated’ with a productivity-increasing technological change. The ‘control’ economy is represented by a model without the technology treatment. The credibility of any simulation turns on getting the structural model right. We address the validation problem by using a Monte Carlo method to test for model validation and conducting sensitivity analysis.23

We implemented the technological-change experiment by increasing the shift parameter in the cotton production functions of both poor and non-poor households.24 Such productivity gains might be achieved through a variety of interventions, including agricultural extension services that teach cotton farmers better techniques and the introduction of higher quality seeds. We simulated a 25 per cent increase in productivity for all cotton producers. While this is a substantial increase in productivity, evidence suggests that delinted UKM08 seeds increase the percentage of cotton lint generated from each kg of cotton from 35 to 44 per cent.

Table 5 reports the simulation results on changes in cotton production, prices and value of production by activity and household under two

23 Section 1 in the Supplementary Materials contains the details of how we conduct our validation tests and sensitivity analysis.
24 See Taylor and Filipski (2014) for more on the production functions used in LEWIE.
scenarios. The base scenario assumes that gins are at maximum capacity ($M = \bar{M}$); thus, any additional supply decreases the seed cotton price, as in the theoretical model. The other scenario allows for excess capacity in the gin sector ($M < \bar{M}$), ensuring that seed cotton prices remain unaltered following the productivity change. In Table 6, we report the changes in total income in the local economy and in each household group. Simulated values are reported with a 90 per cent confidence interval constructed using a Monte Carlo method and the standard errors from the regression results, as described in Taylor and Filipski (2014).

### Table 5. Production impacts of a 25 per cent increase in cotton productivity

| % change in production | Base model (at maximum gin capacity) $M = \bar{M}$ | Model with excess gin capacity $M < \bar{M}$ |
|------------------------|-------------------------------------------------|---------------------------------------------|
|                        | Estimate                                        | 90% confidence intervals                   | Estimate                                        | 90% confidence intervals                   |
| A. Total               | 3.43% (3.43%, 3.43%)                             |                                             | 8.91% (8.91%, 8.91%)                            |
| B. Total cotton        | 19.33% (13.77%, 23.72%)                          |                                             | 39.22% (32.60%, 47.79%)                        |
| % Change in cotton price | $-27.44\% (-33.85\%, -21.81\%)                 |                                             | 0.21% ($-5.68\%, 4.33\%)                       |
| % Change in production value |                                                  |                                             |                                                  |
| A. Total               | 0.16% ($-2.84\%, 3.15\%)                        | 13.62% (9.52\%, 18.05\%)                   |
| B. By activity         |                                                |                                             |                                                  |
| Cotton                 | $-13.41\% (-24.74\%, -3.26\%)                  | 39.51% (25.07\%, 54.19\%)                  |
| Crop                   | 2.12\% (0.75\%, 3.69\%)                        | 8.30% (6.24\%, 10.79\%)                    |
| Livestock              | 1.94\% (0.50\%, 3.46\%)                        | 8.44% (6.98\%, 10.02\%)                    |
| Retail                 | 2.65\% (1.04\%, 4.50\%)                        | 9.09% (5.74\%, 12.63\%)                    |
| Services               | 3.68\% (1.63\%, 5.87\%)                        | 12.02% (8.72\%, 15.86\%)                   |
| Production             | 3.51\% (1.60\%, 5.65\%)                        | 10.93% (7.98\%, 14.30\%)                   |
| Gin                    | 18.42\% (9.28\%, 27.68\%)                      | 42.85% (37.57\%, 51.47\%)                  |
| C. By household        |                                                |                                             |                                                  |
| BPL cotton farmers     | $-4.84\% (-10.77\%, 0.68\%)                   | 22.51% (15.29\%, 29.59\%)                  |
| APL cotton farmers     | $-2.03\% (-6.12\%, 1.84\%)                    | 16.64% (11.38\%, 22.05\%)                  |
| BPL non-cotton farmers | 2.14\% (0.73\%, 3.71\%)                       | 8.39% (6.46\%, 10.59\%)                    |
| APL non-cotton farmers | 2.35\% (0.89\%, 3.94\%)                       | 8.80% (6.53\%, 11.23\%)                    |
| Business               | 1.75\% (-1.30\%, 4.99\%)                       | 14.73% (10.13\%, 20.46\%)                  |
| Labourer               | $-0.50\% (-4.20\%, 3.19\%)                    | 15.84% (10.63\%, 21.85\%)                  |
| D. Cotton by household |                                                |                                             |                                                  |
| BPL cotton farmers     | $-13.48\% (-24.83\%, -3.27\%)                 | 39.37% (25.79\%, 52.18\%)                  |
| APL cotton farmers     | $-12.93\% (-23.85\%, -3.13\%)                 | 37.71% (23.98\%, 51.37\%)                  |
| Business               | $-16.02\% (-29.13\%, -4.09\%)                 | 50.82% (28.37\%, 77.66\%)                  |
| Labourer               | $-13.34\% (-25.01\%, -3.17\%)                 | 39.01% (25.46\%, 53.45\%)                  |

The first column for each case shows the point estimates, and the second column shows 90% confidence intervals (CIs) around simulated outcomes.
| % Change in income | Base model (at maximum gin capacity) | Model with excess gin capacity |
|--------------------|--------------------------------------|-------------------------------|
|                    | Nominal  90% CI | Real  90% CI | Nominal  90% CI | Real  90% CI |
| A. Total           | 2.41% (0.99%, 3.90%) | 1.36% (0.50%, 2.23%) | 8.92% (7.89%, 10.10%) | 4.98% (4.29%, 5.73%) |
| B. By household    |                        |                        |                        |                        |
| BPL cotton         | 1.48% (−1.92%, 5.18%) | 0.40% (−2.40%, 3.44%) | 16.21% (14.46%, 18.06%) | 11.89% (10.41%, 13.06%) |
| APL cotton         | 0.21% (−2.22%, 2.77%) | −0.79% (−2.67%, 1.13%) | 11.66% (10.39%, 12.62%) | 7.69% (6.54%, 8.45%) |
| BPL non-cotton     | 1.65% (0.60%, 2.75%) | 0.59% (0.14%, 1.04%) | 5.49% (4.69%, 6.55%) | 1.56% (1.04%, 2.20%) |
| APL non-cotton     | 1.56% (0.66%, 2.53%) | 0.49% (0.17%, 0.81%) | 5.38% (4.64%, 6.29%) | 1.43% (1.15%, 1.87%) |
| Business           | 12.79% (11.36%, 14.11%) | 11.73% (10.75%, 12.56%) | 22.55% (20.54%, 25.16%) | 18.57% (16.93%, 20.65%) |
| Labourer           | 2.08% (0.33%, 3.93%) | 1.08% (−0.14%, 2.45%) | 9.35% (8.14%, 10.80%) | 5.70% (4.87%, 6.85%) |

For each case, the first two columns present estimates and confidence intervals on nominal incomes and the last two are the same for real incomes.
7.1. Technological change at maximum gin capacity

In the base case, overall production of cotton expands by 19.33 percent (Table 5). However, the value of cotton output falls by almost 13 per cent for both the APL and BPL cotton-producing groups as the seed cotton price drops by 27 per cent. The lower seed cotton price stimulates gin output and seed cotton demand by 18.42 per cent, similar in magnitude to the increase in cotton production. Total income in the economy increases by 2.41 per cent and 1.36 percent in nominal and real terms, respectively (Table 6). Higher income increases the demand for goods and services, stimulating other income-producing activities, including retail, local crops, local livestock and services (Table 5). These, in turn, increase income for the owners of capital and hired labour, which generates higher-order impacts in the Lake Zone economy.

The distribution of impacts across household groups is unequal. Absolute income rises by 1.48 and 0.21 per cent for BPL and APL cotton producers respectively. Real income, however, increases negligibly for BPL households and actually decreases for APL cotton farmers. Both nominal and real income impacts are much lower than the percentage change in cotton productivity, reflecting both the high level of diversification of the Lake Zone economy and the negative seed cotton price effect. In fact, confidence intervals around the percentage income changes include zero for both groups; thus, we cannot reject the null hypothesis that, given price effects, productivity changes do not affect producer-household incomes.

Despite insignificant income changes for cotton farmers, others in the Lake Zone enjoy positive and significant income gains. The cotton productivity change raises the real incomes of both BPL and APL non-cotton households. Labourer households’ real income increases by 1 per cent. The biggest winners are business households; their income jumps by almost 12 per cent. This result is due to the ownership of productive assets by business households. Labourer households receive a higher income benefit than BPL cotton households because they gain from increased demand for labour, of which they have a greater endowment than BPL cotton households.

This simulation illustrates a classic case in which the chief beneficiaries are not the direct beneficiaries; price changes concentrate benefits in other sectors and households. It is consistent with the finding from studies of impacts of technological change in staple production that markets extract most of the benefits from farmers. This is clearly a concern if a goal of development projects is to promote the productive inclusion of poor farmers.

7.2. Technological change with excess gin capacity

The extraction of benefits from poor farmers can be averted if technological change is combined with the creation of new demand for seed cotton. In Tanzania, excess gin capacity and an exogenous price for cotton lint (perfect competition in the gin output market) potentially create an environment in
which cotton productivity increases without putting downward pressure on
the seed cotton price. In this case, the increase in seed cotton production is
39.22 per cent (column 3 of Table 4), nearly twice as high as in the base
experiment. Because the price does not change, the percentage change in
value of cotton output is 40 per cent, similar to the percentage change in pro-
duction. There is also a larger positive impact on gin production. Although
gins do not benefit from a lower seed cotton price, their production expands
in tandem with the cotton supply, as previously idle gins come on line.

If increased demand prevents the seed cotton price from declining, more of
the benefits of technological change remain within the local economy. Total
income increases by 8.92 per cent in nominal terms and by 4.98 per cent in
real terms. The distribution of income gains across households changes dra-
matically. Now, cotton-producing households enjoy significant income gains.
Nominal income jumps by 16.21 per cent in BPL cotton-producing house-
holds and 11.66 per cent in APL cotton-producing households. Real incomes
also increase substantially.

The income increase in labourer households is also larger than before. Labourer households benefit from higher wages induced by labour demand
in cotton production and other activities, as well as by increases in their own
cotton production. As before, higher incomes stimulate the output of goods
and services demanded by households. All sectors’ production increases by a
significant amount. The increases in food and livestock products, on which
agricultural households spend a large part of their income, are larger in this
than in the base scenario. Business households reap significant gains due to a
high demand for retail goods. Their income rises by 23 per cent in nominal
terms and 19 per cent in real terms, almost 7 per cent higher than in the pre-
vious scenario.

8. Discussion

Our simulations underline the importance of an elastic demand for crop out-
put to ensure that welfare gains from technological innovations remain in
farm households. In the case of small-scale cotton producers in Tanzania’s
Lake Zone, excess demand in the gin sector currently ensures that poor
households benefit from a technological change that raises cotton productiv-
ity. Viewed through a local general-equilibrium lens, it is clear that
productivity-enhancing innovations in other activities, e.g. food crops and/or
livestock, could complement improvements in cotton productivity and raise
real incomes further in an elastic-demand scenario. They might also help
counteract the negative income impacts of lower seed cotton prices in an
inelastic-demand scenario.

As a sensitivity analysis, we simulated a 10 per cent increase in livestock
productivity at maximum gin capacity together with the 25 per cent increase
in cotton productivity, keeping other things constant. Such a scenario
explores the potential effectiveness of complementary policy measures at
counteracting negative price effects in the absence of an elastic demand for
seed cotton. The production and income impacts appear in Tables S3 column (A) and S4.1 of Supplementary Materials, respectively. Livestock is produced and consumed locally at the village level, and increased productivity reduces the prices of local livestock products. At maximum gin capacity, the negative income effects of lower seed cotton prices are offset by lower livestock prices. Income increases significantly for all but cotton-producing APL households, but the latter no longer suffer negative income effects from increased cotton productivity. This analysis shows that interventions in other linked sectors could supplement technological change in cotton production and generate real income benefits even in the absence of an elastic demand for seed cotton. However, they do not address the underlying market constraint that shifts benefits of technological change away from cotton farmers.

Technological improvements in the cotton sector could relay benefits to other crops, if they are associated with improved access to credit and other inputs. For example, land-enhancing cotton intervention in the Burkinabé cotton reform did not lead to sustained income improvements; however, it increased farmers’ access to agricultural inputs for other crops (Kaminski and Thomas, 2011). Our LEWIE simulations presented in Section 6 account for relaxed liquidity constraints on purchased inputs for other crops. Liquidity constraints could diminish cross-crop spillovers from a technological change in cotton production, and this in turn could diminish overall income gains. Sensitivity analyses with liquidity constraints for the base model and for the model with excess capacity appear in Supplementary Material Table S3, columns (B) and (C), and Table S4.2, respectively. The results indicate that imposing a liquidity constraint in the LEWIE model reduces income and production gains, but the reduction is not statistically significant; the percentage change in income for most household groups is within 15 per cent of the original change in the base case. Overall, our findings are robust to changes in liquidity constraints.

The LEWIE model, like most micro agricultural household models (Singh, Squire and Strauss, 1986; Taylor and Adelman, 2003), treats land and capital inputs as fixed in the short run. From a modelling perspective, transaction costs and imperfect or missing markets could result in different prices across households, depending on model closure assumptions. For example, it is possible that in a longer run households might reallocate land across activities or expand cotton production. Dynamic-recursive modelling to capture these effects is beyond the scope of the present analysis. However, we would expect seed cotton demand constraints to limit welfare gains in a dynamic, like in a static, setting, unless those constraints can be alleviated as part of the dynamic solution.

See Taylor and Filipski (2014) for how liquidity constraint is factored in the LEWIE model. In the model, it appears in the second equation of Production Block in Table S10 of Supplementary Material.
The market power of cotton ginning companies is not formally modelled in our analysis. Agricultural economics research has shown that even small degrees of downstream oligopoly and/or oligopsony market power may reduce or eliminate the welfare benefits of support mechanisms (Russo, Goodhue and Sexton, 2011). It may not be critical to factor market power into our model if excess gin capacity results in an (almost) perfectly competitive gin sector. However, at maximum gin capacity, gin market power could further limit welfare gains for cotton farmers as well as linked actors in the local economy. The Tanzanian cotton board, recognising this, regularly monitors the prices received by cotton farmers and also sets a minimum price in every buying season. Planned future research will employ a LEWIE approach to explore the implications of gin market power for cotton farmers as well as for the local economy as a whole. This will require detailed data on cotton ginning companies, cost function estimates for cotton gins, and explicit modelling of gin market structure within a LEWIE framework.

9. Conclusion

Technology change holds the potential to increase crop output and incomes, but traditionally most of the benefits of higher food-crop productivity have been transmitted away from farmers via lower food prices. Our LEWIE results suggest that the same is likely true for technological change in non-food cash-crop production. Lower prices dampen the impacts of technology change on cash-crop production, and they transmit benefits away from farmers without benefiting them as consumers. At our Tanzania study site, cotton gins and the business households connected with them benefit from lower seed cotton prices resulting from technological change on cotton farms, but this comes at the cost of smaller production and income impacts in the local economy. If the gin demand for seed cotton is inelastic, complementary interventions may be necessary to ensure that benefits from technological change remain in poor farm households. Studies by Collier and Dercon (2014), Pingali (2007) and Binswanger and von Braun (1991), for example, emphasise the importance of establishing proper infrastructure and adequate demand to absorb increases in crop supply.

In our base simulations, which permit prices to adjust to changes in local seed cotton supply, we cannot reject the null hypothesis that cotton-producing households fail to reap income gains from higher cotton productivity. Currently, excess capacity in the gin sector creates an elastic demand for seed cotton. If the demand for seed cotton expands sufficiently to avert price declines, we find statistically significant impacts on cotton production, the welfare of cotton-producing households, and income spillovers to other households in the Lake Zone economy. Complementary interventions focusing on other linked sectors can help offset negative income effects due to inelastic demand in the cotton sector, but their effect is limited as long as markets do not expand to absorb increases in cotton output.
The message from this study is clear: Technological change that raises productivity in cash crops is not likely to achieve the goal of significantly raising incomes and welfare in poor farm households, or in the communities of which they are part, unless market demand expands in tandem with induced output gains. Interventions to ensure markets for increased output need to be a fundamental part of productive inclusion strategies.

Supplementary data

Supplementary data are available at European Review of Agricultural Economics online.

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