On the Economic Impact of Malaria Control, some Discordant Evidence

Richard Sedlmayr*

May be cited as working paper version 13 Jan 2014

This cluster randomized trial evaluates the economic impact of a private sector malaria control program. In collaboration with 81,597 smallholder contract farmers in 1,507 clusters, I investigate whether the distribution of free insecticide-treated mosquito nets at the outset of malaria season increased cotton output sufficiently to be commercially viable for the implementing agribusiness. But despite large health effects in farming households, I do not detect any impact on deliveries to the agribusiness. I conclude that the independent and sustained distribution of free mosquito nets by Zambia's cotton industry is unlikely to materialize without subsidies. The results can be partially reconciled with previous research on the labor decisions of smallholder farmers, and tend to side with the minority of the observational literature that questions the role of malaria as a central and immediate cause of poverty.

KEYWORDS: malaria, smallholder, outgrowers, contract farming

JEL CODES: C930, Q120, I390

ACKNOWLEDGEMENTS: This study would not have materialized without the support of John Miller, Guenther Fink, and Andrea Lozano, Mwela Namonje, Nguli Zulu, Rick Steketee, Duncan Earle, Rodrick Masaiti, Charles Hayward, Nigel Seabrook, and Zambia's National Malaria Control Centre. Financial support from the Program for Appropriate Technology in Health (PATH) is gratefully acknowledged.

CONFLICTS OF INTEREST: None.

ETHICS COMMITTEE APPROVAL: This study was approved by PATH REC and UNZA REC.

TRANSPARENCY AND REPRODUCIBILITY: This trial and its main outcome variables were recorded in a public trial registry before the underlying data became available (clinicaltrials.gov identifier: NCT01397851). Study instruments and supplementary materials can be found on the Open Science Framework ("The Outgrower Opportunity"). Data and code will be made available upon peer reviewed publication or on June 1st, 2015 at the latest. No observations have been excluded.

*richard.sedlmayr@gmail.com

Background and Rationale

Malaria correlates with poverty, but identifying causality is challenging. While malaria has been widely presented as a heavy drag on economic development (Bloom & Sachs, 1998), (Gallup & Sachs, 2001), (WHO, 2001), (Sachs & Malaney, 2002), (Bloom & Canning, 2005), a smaller body of research calls this narrative into question (Weil, 2007), (Acemoglu & Johnson, 2007), (Ashraf, Lester, & Weil, 2008).

Regardless of the moral case for reducing the burden of malaria, there is a pressing need to understand its economic impact. For instance, if it is true that malaria reduces economic output by decreasing the availability and productivity of labor, the private sector may be able to internalize the benefits of malaria control to some degree (Roll Back Malaria , 2011). The guiding idea of the research presented here is that such evidence could open a path towards financial sustainability.

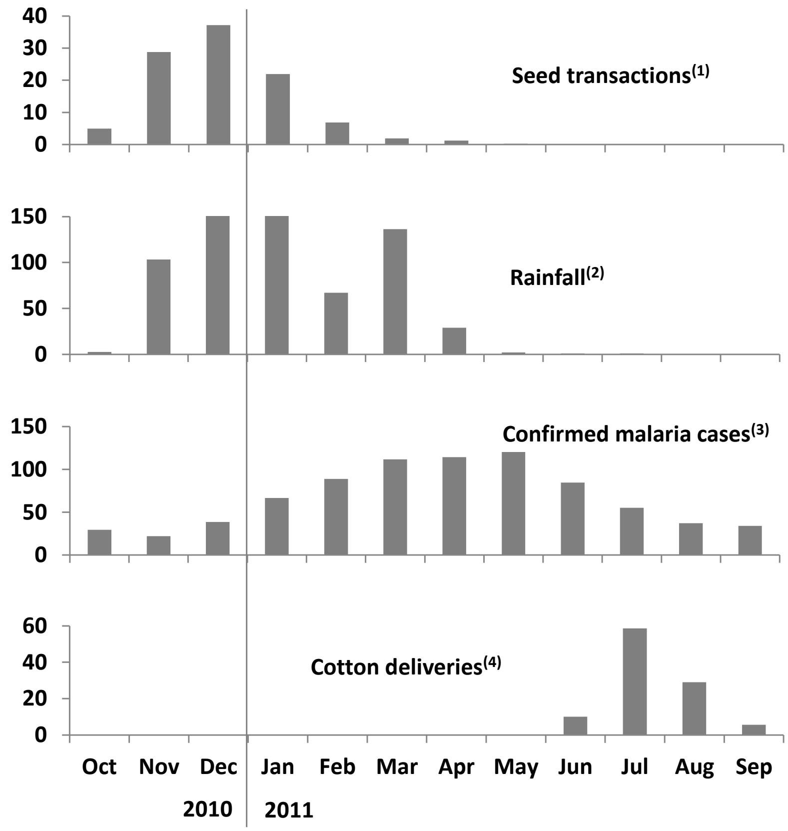
Specifically, if a credible link between malaria control and agricultural output could be established in the Zambian cotton sector, ample opportunities for scale would present themselves. Research by the World Bank suggests that over much of last decade, approximately 300,000 Zambian households grew cotton in contractual arrangements with private agribusinesses (Tschirley & Kabwe, 2009). In these so-called outgrowing agreements, companies offer smallholder farmers agricultural inputs in exchange for a commitment to deliver crop. Even a modest increase in cotton deliveries could make the provision of mosquito nets a commercially viable intervention that might be sustained without public or philanthropic support. This study evaluates this conjecture in more detail, using a large-scale randomized trial.

Study Context

As illustrated in Figure 1, Zambia experiences only one rainy season, with rainfalls usually starting in early November, peaking in January, and ceasing again in April. The pronounced fluctuations strongly affect malaria transmission, with the burden of the disease following the rains with a time lag.

The climactic fluctuations also determine the annual agricultural cycle: field work generally starts with the return of the rains in November, and most planting is done in December. This is also the time when contract farmers in Zambia's cotton industry obtain the bulk of their seed, as displayed in Figure 1. The most labor-intensive field activities, such as weeding and crop spraying, continue through the peak of the malaria season. Cotton harvests start in May, and are followed by several months of cotton deliveries by the farmers to the ginning companies.

Figure 1: Study period



(1) In thousands of transactions. Source: Dunavant Cotton
(2) Average rainfall in mm in study area (as defined by coordinates of survey respondents). Source: FEWS NET
(3) Sum of confirmed malaria outpatient discharges, inpatient discharges, and deaths in health facilities across Zambia's Southern, Eastern, Lusaka, and Central provinces, in thousands. Source: Zambia District Health Information System
(4) In thousands of tons. Source: Dunavant Cotton

Dunavant Zambia Limited ("Dunavant") is the largest player in Zambia's cotton industry, competing with half a dozen other companies.[1] Its core business is the purchase of cotton; cotton ginning; and the sale of cotton lint. Dunavant manages a vast network of contract farmers, amounting to over 100,000 in the 2010-11 season. At the village level, farmers are managed by so-called distributors who serve as a liaison between Dunavant and the farmers. In the 2010-11 season, Dunavant worked with 1,507 distributors, organized into 62 sheds across the 9 cotton growing regions.

Dunavant operates a credit-based outgrowing scheme. At the beginning of a season, farmers sign contracts that allow them to obtain seed and pesticides, but occasionally also fertilizer, tools, and other

[1] In 2013, *Dunavant Zambia Ltd* was acquired by *NWK Group* and re-branded to *NWK Agri-Services*.

inputs, in the form of an interest-free loan from Dunavant. In return, farmers contractually commit to delivering their entire harvest of seed cotton to Dunavant at the end of the harvesting season; the value of the loan is deducted from the crop value, and the residual is paid out in cash.

In practice, farmers have the option to side-sell to other parties than the ones they originally contracted with, as several buyers compete in overlapping territories and contract enforcement is usually not viable. Dunavant therefore effectively competes for cotton at harvest time, and the pricing of unprocessed farmgate cotton is by and large determined by world spot prices.

In the 2010-11 season, Dunavant ended up paying a stable 3,350 ZMK (0.70 US$) per kg of cotton; a price of 3,200 ZMK (0.67 US$) was applied for loan amortization purposes. No quality premiums or discounts were applied.

Table 1: Cotton delivery, loan, and payment data, 2010-11 season (control group)

	Median values	Mean values
Cotton deliveries	382.00 kg	548.35 kg
Total loan(1)	29.26 US$	39.28 US$
Loan repayment(1)	29.26 US$	37.96 US$
Farmer's final cash receipts(2)	236.79 US$	344.12 US$

(1) The exchange rate of 4,785.47 ZMK per US$ is applied throughout this paper.
(2) Calculated as (cotton deliveries – (loan repayment / amortization price)) x farmgate cotton price

Study Purpose

The primary study purpose was to evaluate whether independent private sector malaria control efforts would be viable for Zambia’s cotton industry. This industry has not traditionally carried out malaria control operations. However, given its extensive distribution network to vulnerable populations, it is exceptionally well positioned to conduct distributions of insecticide-treated mosquito nets, a proven and highly effective method for reducing malaria incidence (Lengeler, 2004).

It was expected that smallholder’s willingness to pay for nets would be minimal, which was why nets were distributed for free. Nonetheless, it was hoped that that this would pay off commercially: malaria is endemic throughout Zambia’s cotton growing regions; cotton growing (and weeding in particular) is most labor-intensive during the months when malaria incidence peaks; and cotton ginning is a volume-driven business involving significant fixed costs but positive margins on cotton volume.

In the distribution studied here, the cost of purchasing and distributing a net amounted to approximately five dollars (Sedlmayr, Fink, Miller, Earle, & Steketee, 2013). As of June 2011, Dunavant's budgeting systems suggested that a one-time season-end increase of 22 kg in average deliveries per farmer would be sufficient to neutralize this cost. Costs would be further defrayed through a reduction in loan defaults.

In collaboration with Dunavant, a valuation model was designed to establish the commercial impact of any increases in cotton deliveries and repayment rates. It was agreed that if the intervention would prove commercially viable based on the research results and this tool, Dunavant would purchase mosquito nets and distribute them to its contract farmers for free in future seasons.

Methods

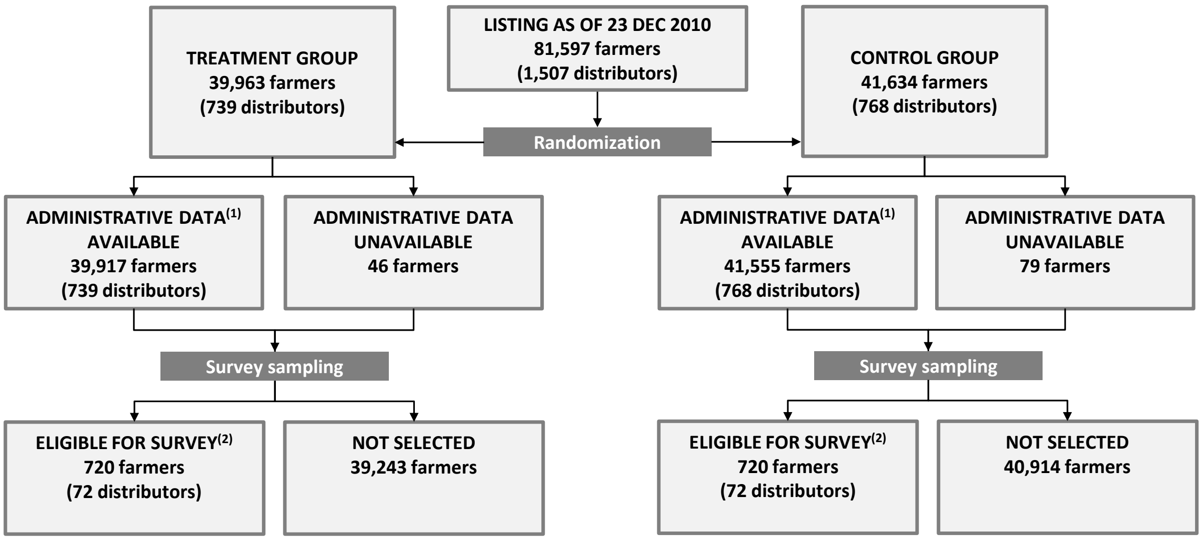
Study Population

The study population was composed of all farmers having a standing contract farming agreement with Dunavant Cotton for the 2010/11 season on December 23, 2010. By this time, 81,597 annual contracts associated with 1,507 distributors were registered in Dunavant's database. Farmers whose contracts had not been processed by the cutoff date in December 2010 were not recruited into the study.

Study Design

The study used a randomized design as illustrated in Figure 2, clustering treatment at the distributor level. In order to ensure a balanced roll-out across regions, the 62 sheds were treated as separate strata in the randomization.

Figure 2: Study design



(1) Administrative data includes loan, loan repayment, and cotton delivery transactions for the 2010-11 season.
(2) Survey data includes demographic and health information, data on mosquito net ownership, and two-year maize yields. For more information on survey implementation, see (Sedlmayr, Fink, Miller, Earle, & Steketee, 2013).

Study Procedures

Following the randomization, bed nets were distributed between January 20th and January 28th 2011. As a fair and simple distribution rule, it was determined that each treatment household would be eligible for exactly one bed net through the program.

In order to verify the accuracy of the distribution, and to evaluate its health impact, a household survey was conducted between June 20th and July 11th 2011 in a randomly selected subset of clusters. The survey process is described in more detail elsewhere (Sedlmayr, Fink, Miller, Earle, & Steketee, 2013).

Registered Outcome Measures

Outcome measures were recorded in a public trial registry before the post-intervention data could be analyzed (clinicaltrials.gov identifier: NCT01397851).

Cotton deliveries. The primary outcome measure is cotton output at the farmer level, as measured by the weight of the farmer's 2010-11 season cotton deliveries recorded in the company's administrative data collection systems. Cotton deliveries may not be identical to true cotton yield, as farmers have the option to side-sell a share of their cotton to other buyers in breach of their Dunavant contract. For the core purpose of the study, which is to determine the commercial viability of the intervention from Dunavant's perspective, farmer's cotton deliveries are more relevant than true cotton yield.

Contract defaults. As mentioned, cotton deliveries are used to amortize farmer's input loans before cash payments are made for excess cotton. If a farmer's delivery fails to meet this threshold, Dunavant has no other means of recovering the loan and needs to write it off as a full or partial default. This adds to the economic cost of a delivery shortfall. However, as illustrated in Table 1, loans were small and defaults relatively rare.

Maize yield. In 2010-11, Dunavant did not have a commercial interest in maize and did not collect data on this crop. However, over 99% of surveyed farmers grow maize, and the survey offered the opportunity to collect self-reported yield data.

Self-reported malaria incidence. In order to measure the health impact of the net distribution, self-reported fever and confirmed malaria data were collected for survey respondents, as described in more detail in (Sedlmayr, Fink, Miller, Earle, & Steketee, 2013).

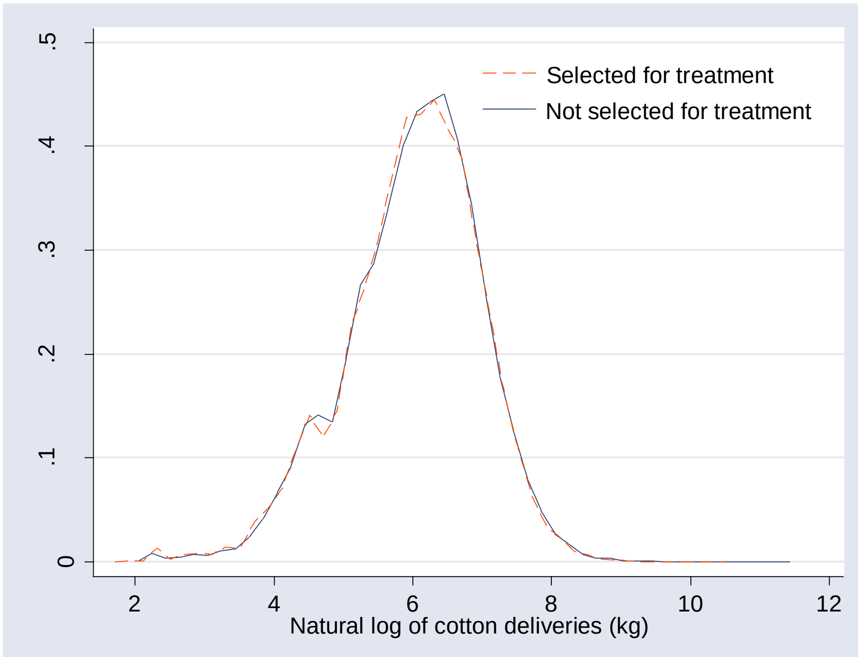
Results

Balance checks on the household characteristics, distribution accuracy, and the health impact of the intervention have been extensively documented in a separate publication (Sedlmayr, Fink, Miller, Earle, & Steketee, 2013). The treatment and control groups are well balanced with regards to baseline household and farm characteristics. Administrative data from Dunavant's database suggests that the groups were also well balanced in terms of loan sizes for seed ($p=0.30$) or pesticides ($p=0.53$). The household survey audited the accuracy of the distribution and found it to be acceptable: 4.6% of households in the treatment group reported not having received a net from Dunavant.

The intervention had a large health impact, showing a 42 percent reduction in the odds of self-reported fever ($p<0.001$) and a 49 percent reduction in the odds of self-reported malaria ($p=0.002$) in the treatment group (Sedlmayr, Fink, Miller, Earle, & Steketee, 2013).

Density functions of cotton deliveries in the treatment and control groups are depicted in Figure 3; differences can barely be discerned.

Figure 3: Cotton deliveries (based on 81,472 observations)



I evaluate the impact of the cotton distribution using (1) a simple linear specification; (2) a linear specification using input loans for seed and insecticide as covariates; (3) given the distribution of the dependent variable, a logarithmic specification; and (4) given the distribution of the covariates, a log-log specification.

Table 2: Impact on cotton deliveries

Linear specifications			Logarithmic specifications		
Specification	(1)	(2)	Specification	(3)	(4)
	deliveries	deliveries		ln(deliveries)	ln(deliveries)
treated	-4.05 (13.88)	2.14 (11.38)	treated	-0.014 (0.022)	-0.010 (0.020)
seed loan		21.22*** (4.25)	ln(seed loan)		0.392*** (0.015)
pesticide loan		11.26*** (1.71)	ln (pesticide loan)		0.554*** (0.013)
constant	548.35*** (10.52)	68.70*** (16.99)	constant	6.007*** (0.015)	3.411*** (0.044)
Observations	81,472	81,472	Observations	72,446	60,764

Notes: Deliveries are denominated in kg, loans in US$. For farmers in the treatment group, the variable *treated* was coded to 1. To adjust for the spatial correlation of regression residuals, standard errors were clustered at the distributor level. Robust standard errors are in brackets. *** → $p<0.01$

Cotton deliveries are *lower* in the treatment group by 4.05 kg. The effect is insignificant using all of the above specifications.

To stress-test this result, I repeatedly simulate the randomization process under the assumption of a specific true treatment effect that is assumed to hold for all subjects. In the first specification of Table 3, I assume a true treatment effect of null ('sharp null hypothesis'); in the second specification, I assume a true treatment effect of minus 4.05 kg (which allows for the construction of confidence intervals).

Table 3: Randomization inference

	Estimated treatment effect (percentiles)						
True treatment effect	1st	5th	25th	50th	75th	95th	99th
(1) 0 kg	-12.82 kg	-9.09 kg	-3.80 kg	0.05 kg	3.86 kg	9.21 kg	12.98 kg
(2) -4.05 kg	-17.10 kg	-13.12 kg	-7.72 kg	-4.04 kg	-0.04 kg	5.39 kg	9.48 kg

Note: 10,000 simulations per specification

Confidence intervals are substantially narrower than those implied by the regressions in Table 2. However, I remain unable to reject the null hypothesis ($p=0.23$).

To estimate the impact of treatment on the incidence of loan defaults, I use logarithmic regression. As displayed in Appendix A1, the odds ratio coefficients are not significantly different from one: no impact can be detected. This is not a major surprise: as Table 1 illustrates, full loan repayment is the norm.

Appendix A2 illustrates that no effects can be picked up on maize yield, either. Clearly, as these regressions are based only on survey and not administrative data, the sample is small and statistical underpowerment is a real risk; however, it is worth noting that effects can be picked up on other potential explanatory variables, such as the incidence of reported crop damage by pests and by people (i.e., theft or vandalism).

Discussion

I summarize a number of findings.

The intervention had a substantial health impact. As a side note, the results are not consistent with the WHO position that communities are only effectively targeted through universal coverage, i.e., by making exactly one net available for each uncovered sleeping space (World Health Organization, 2007); in the case at hand, providing one net to each cotton farmer (without taking into account household- or village-level coverage ratios) appears to have reduced malaria incidence dramatically, and given the low administrative cost of this approach, cost-effectiveness (in terms of cost per case averted) was extraordinarily high (Sedlmayr, Fink, Miller, Earle, & Steketee, 2013). This suggests that similar opportunities to reduce malaria incidence at the margin should not be dismissed in the future.

The intervention was not commercially viable for the agribusiness. The program failed to meet the benchmarks set out by the valuation model. This cannot be attributed to low malaria incidence: over the course of the study period, the average rates of reported fever and malaria incidence were 24% and 12% in the control group (compared to 15% and 6% in the treatment group). As discussed, both of these health effects are highly significant.

There is no indication that the intervention increased farmers' incomes. As the intervention averted more than one malaria case per household per month on average over the study period (Sedlmayr, Fink, Miller, Earle, & Steketee, 2013), it must have freed up substantial time in the treatment households. Yet cotton deliveries did not increase, which begs an explanation.

One argument holds that cotton deliveries to Dunavant may not be equivalent to farmer's true cotton yield: a discrepancy between cotton deliveries and true cotton yield is possible, as any household could choose to side-sell a share of their true cotton yield instead of honoring their contractual obligation with Dunavant. However, there is no compelling reason to believe that side-selling should be positively related to treatment status; if anything, one would expect farmers who receive a free bed net from Dunavant to reciprocate by side-selling less, not more.[2]

If one accepts cotton deliveries as an acceptable proxy for farmer's cotton production, one might still argue that it does not provide a complete picture of farmer's income. Perhaps households tend to soften the impact of malaria on cotton yields by re-allocating time from other economic activities in times of hardship, so there could have been effects on non-cotton income. But I have no adequate basis for this conjecture, and to the extent data allows for its investigation, it does not hold up: in particular, I am unable to detect an impact on reported maize yields, which (together with cotton) account for the majority of economic value generation in extensively surveyed cotton growing regions of Zambia (Fink & Masiye, unpublished data).

A third explanation suggests that the impact on income was simply too small to be detectable, despite the study's large sample size and power. This might be the case if the marginal product of labor was extremely low in the context at hand, which would imply that farmers were typically constrained in terms of farming inputs or land, rather than labor. However, this also implausible: Zambian cotton farmers are (given Dunavant's input financing system) not constrained in the access to inputs, and only rarely consider themselves constrained in terms of available land. Consistent with literature on the economics of smallholder farming (Cleave, 1974), farmers typically identified expected labor constraints as the primary factor in determining plot size (Fink & Masiye, unpublished data).

As none of the above explanations are satisfying, I conclude that there was no impact on farmer income, and that better health led to more leisure.

This can be reconciled with previous work on the labor decisions of smallholder farmers (Fafchamps, 1993) which helps explain why farmers who are concerned about labor constraints may still have the capacity to mobilize substantial labor reserves. The model plausibly assumes that farmers value leisure,

[2] One exception to this argument might hold for the 4.6% of treatment households who had been allocated to the treatment group, but did not end up receive a net. However, controlling for leakage (and ignoring the possible selection bias in doing so) does not render treatment effects significant.

and labor choices are viewed as the result of a dynamic optimization process in response to a series of exogenous shocks. It can be taken as a basis for arguing that malaria typically enters the production function not via actual, but via expected labor constraints (for which farmers make allowances in the process of determining plot size); and by extension, that the nets in in the study at hand may have arrived at a time when plot sizes had been determined - too late to have an impact on the production of most farmers in the study season 2010-11. But in subsequent seasons, one might expect the treatment group to anticipate reduced labor constraints, plant more aggressively, and achieve higher yields – and this is not borne out: to the extent I am able to match study farmers to the 2011-12 study database[3], re-running the regression specifications from Table 2 continues to estimate insignificant treatment effects.

A more speculative explanation for farmer's apparent labor reserves could build on a reference-dependent non-optimizing behavioral model, in the spirit of Aspiration Adaptation Theory (Selten, 1998). Farmers may only aspire to limited yields, but if illness triggers an experience of perceived shortfall or loss, they may compensate aggressively and with little concern for leisure smoothing across individuals or over time. Like Fafchamps' model, this could explain why farmers are able to absorb labor shocks; however, it does not imply that effects should materialize in subsequent seasons.

Conclusion

Given the study's experimental and pre-registered design, as well as its large sample size, its results seem to strike a loud discord with widespread narratives about the economic burden of malaria, and provide some support to the conjecture that identification problems hamper the underlying observational literature. This should in no way be misread to suggest that malaria control might not be worthwhile, in general or in the case at hand. Indeed, at an estimated $0.21 per malaria case averted, the health impact of the net distribution was extraordinary (Sedlmayr, Fink, Miller, Earle, & Steketee, 2013). Dunavant and other cotton outgrowing agribusinesses have the potential to serve as cost-effective vehicles for malaria control, but like most other malaria control opportunities, the realization of this potential depends crucially on continued public or philanthropic funding.

More generally, it appears that even though Southern African smallholder cotton farmers identified labor as a binding constraint on production, they had the capacity to absorb labor shocks. While this can be reconciled with previous work with smallholder farmers West Africa, the lack of longer-term effects

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[3] I am able to match 47,272 study subjects between databases via national registration card numbers.

remains a puzzle. The labor decision-making process of smallholder farmers is worthy of further study, as it has important repercussions for the merit of numerous development interventions.

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Appendix

Table A1: Impact on defaults

	(1)	(2)
	full default	partial default
treated	0.887	1.031
	(0.097)	(0.116)
Observations	81,472	81,472

Notes: Among the 39,963 farmers in the treatment group, the variable *treated* was coded to 1. Among the farmers who did not deliver any cotton, the variable *full default* was coded to 1. Among the farmers who delivered some cotton, but an insufficient amount to defray the loan, the variable *partial default* was coded to 1. Coefficients are odds ratios.

Table A2: Impact on maize yields

Specification	(1)	(2)	(3)	(4)	(5)	(6)
	bags	bags	bags per hectare	bags per hectare	bags increase	bags increase
treated	-5.21 (9.72)	-0.96 (13.31)	-3.66 (3.23)	-2.99 (3.78)	0.068 (0.099)	0.041 (0.105)
damage - flood or drought		-16.68 (20.11)		3.72 (4.15)		-0.166 (0.144)
damage - animals		-3.94 (13.90)		1.72 (5.31)		0.007 (0.123)
damage - pests		-6.72 (16.59)		1.40 (4.39)		-0.290** (0.140)
damage - people		-13.73 (32.68)		29.99 (24.12)		-0.722** (0.350)
damage - other		16.33 (17.56)		-2.15 (4.13)		0.000 (0.138)
constant	58.97*** (6.06)	62.19*** (14.80)	36.04*** (2.51)	31.61*** (4.56)	0.207*** (0.051)	0.364** (0.144)
Observations	787	574	700	485	715	494

Notes: The variable *bags* quantifies the numbers of bags of maize harvested by the survey respondent's household in the 2010-11 season. The variable *bags increase* refers to the increase in this variable observed between the 2009-10 and 2010-11 seasons. The control variables showing the word *damages* are dummies that are coded to 1 if the household reported a damage of this type to its farming plot during the 2010-11 season. Variations in the number of observations between the various specifications can be attributed to the fact that the response "don't know" was an option on the questionnaire. To adjust for the spatial correlation of regression residuals, standard errors were clustered at the distributor level. Robust standard errors in are brackets. ** → $p<0.05$; *** → $p<0.01$