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Ex post evaluation of technology diffusion in the African palm oil sector: The Caltech expeller in Cameroon, Benin, and Liberia

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ABSTRACT

This study is a post-project evaluation of three development projects promoting the same technology but implemented at three different times and locations over a period of thirty years, from 1984 to 2014. The technology in question is a small, portable palm oil expeller invented in Cameroon in the 1980 s. The technology was designed to increase the productivity of small farmers and create employment opportunities by increasing local capacity for small-scale palm oil processing. The expeller was subsequently promoted in Benin and Liberia over a period of nearly two decades. This evaluation is based on archival research of institutional records, data from impact surveys of technology users in all three countries during the project periods, and field research in Liberia in 2011 and 2013. The study analyzes and evaluates the social, economic, and environmental impacts of the expeller over the long term, comparatively, across a broad geographic area. In terms of social and economic impacts, the technology consistently increased incomes for farmers and small enterprises. The use of the technology altered relationships of production, particularly with regard to the role of women in palm oil processing and their control over resources. Environmental impacts of the technology are geographically dispersed and include increased water usage and pollution. Ultimately the technology in question has also contributed to political impacts over time by exacerbating conflicts between small farmers, palm oil corporations, and governments. This study confirms that comparative, longitudinal evaluation research can reveal important dimensions of development impacts.

1. Introduction

A major problem associated with measuring and explaining the impacts and sustainability of international development activities involving technology diffusion is that data collection is halted once a project has ended and it becomes a financial challenge to implement longitudinal research. Impact evaluation frameworks fit short project timescales that are often five years or less and provide detailed information about the beginning phases of processes of technological change. The incremental and cumulative impacts of diffusion and adoption may occur over decades rather than years, slowly yet inexorably contributing to widespread social transformations. For example, the long-term impacts of policies and programs guiding international development efforts in the 1970 s and 1980 s can only now begin to be objectively assessed in terms of social, economic, and environmental sustainability. In many instances, the profound gap in knowledge concerning the long-term and spatially diffuse impacts of technology for development is due to a lack of post-project evaluations. This research problem has vexed development experts for many years. According to Hyman and Corl (1984), performing a post-project (*ex post*) evaluation of technology projects can contribute to development planning and decision-making by indicating whether technologies have continued to be used in a project area or even spread to other places without external assistance. Such studies may assist in the design of complementary projects in the project area and replications elsewhere, help to identify people adversely affected by the project, or mitigate unintended environmental impacts. More importantly, post-project evaluations may inform more nuanced and effective decision making to meet both short and long-term policy and program goals. Although institutional interest in post-project research has increased over the past decade there remains a strong need for empirical evidence of the sustainability of development policies and practices to inform results-based programming.

This study uses a post-project evaluation framework to analyze and explain the social, economic, and environmental impacts of a series of projects that took place over a thirty-year period. Drawing

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on data from three projects that used the same technology diffusion and economic development strategy, the study moves beyond evaluating a single development activity to compare impacts across projects, and over time, with the goal of elaborating more strategic lessons for the theory and practice of development (Bebbington, 2003). The findings could contribute to more nuanced policy and decision-making, particularly for agencies and institutions promoting technology diffusion. The findings of this study are particularly relevant to agencies and institutions supporting smallholder farmers and small businesses as a means of stimulating economic development. What are the medium- and long-term social and environmental impacts of agricultural technology change and do they complement or compete with the economic goals of such projects? What about the political ramifications of promoting technologies innovated for smallholders rather than for the interests of global agricultural corporations? As this study will suggest, the political impacts – rather than social and environmental impacts – of technology policies and programs for development can ultimately undermine the intended results of assisting smallholder farmers.

Between 1984 and 2014, the U.S. Agency for International Development (USAID) funded three separate development projects in Cameroon, Benin, and Liberia to promote the diffusion of a low-cost technology intended to benefit small-scale palm oil producers. Using a commercial approach to technology diffusion, the goal of the projects was to establish localized supply chains in the palm oil producing regions in each of these countries to promote the diffusion of a mechanical palm oil expeller. The three projects were implemented by three different development institutions in three countries during different periods of time, yet the implementation strategy and evaluation methodology guiding the projects remained consistent to the extent that comparison across projects is feasible. The chronological sequence of the three projects over a period of thirty years and the spatial distribution of the project activities across a subregion in Africa provides a unique opportunity to evaluate the short-, medium-, and long-term impacts of technology diffusion in the oil palm sector. Rather than analyzing only the immediate impacts during the project period, this study explains the lifecycle of the technology after project termination and withdrawal of subsidized assistance.

The first project to promote the small-scale palm oil expeller began in 1984 in Cameroon (Hyman, 1988, 1990, 1992). The United States government provided funding to Appropriate Technology International (ATI) and its partner Association for the Promotion of Community Initiatives in Africa (APICA) to assist Cameroonian farmers to add value to their oil palm crops. An international engineering team created small-scale palm oil expellers for individuals and small businesses, designed to increase processing efficiency (Fig. 1). The project trained local metal fabrication shops in the manufacture and commercialization of the technology, and provided ongoing technical support until the program in Cameroon ended. USAID later funded two more country-based programs to promote the palm oil expeller. One was in the Republic of Benin from 1998 to 2003 called the Benin Oils Project and implemented by EnterpriseWorks Worldwide/Appropriate Technology International (Adégbola, Singbo, Ahouansou, and Savi, 2003; ATI/Benin, 2002; Savi, Adégbola, & Akplogan, 2004). The next program was in Liberia from 2008 to 2014, where two projects, the Liberia Smallholder Oil Palm Revitalization Project (LSOPRP) and Smallholder Oil Palm Support (SHOPS), were implemented by Winrock International (Winrock) under subcontracts to the International Institute for Tropical Agriculture (IITA) and ACDI/VOCA, respectively (Bishop, Ben Diallo, and King 2010; Bishop 2014) (Fig. 2 and Table 1).

Thirty years later farmers in Cameroon farmers and entrepreneurs continued to purchase and operate the palm oil machine

Fig. 1. Promotional demonstration of the vertical Caltech expeller in Liberia; Source: Varney Seasay 2010.

invented during the initial project (Nchanji, Tataw, Nkongho, & Levang, 2013; Nkongho, Nchanji, Tataw, & Levang, 2014). In southern Benin, a large and successful agricultural fabrication shop in Porto Novo is still manufacturing and selling the expeller and local engineers were recently working on complementary technologies to boost its utility (Godjo, personal communication May 16, 2012). In Liberia, 480 machines were sold between 2008 and 2014 (Bishop et al., 2010; Bishop, 2014). USAID funded a second phase of the Smallholder Oil Palm Support project from 2015 through 2018, implemented by ACDI/VOCA (ACDI/VOCA, 2018). Through a combination of efforts on the part of appropriate technology practitioners, metal fabricators, and technology users, the palm oil expeller has been widely diffused throughout a broad geographical region. The technology has circulated for a period of thirty years, for much of that time without any type of subsidized development aid.

Given the persistence of the technology over a span of decades and the wide area of diffusion, it is important to analyze the social, economic, environmental, and political impacts related to its use in order to understand whether the program funders and implementing organizations achieved their intended outcomes. In response to the early call from Hyman and Corl (1984), this study also helps to identify people adversely affected by the project and locates unintended environmental impacts not captured in previous studies concerning the technology. This research also reveals important political dimensions of technology diffusion that were in fact predicted well in advance and yet have only become apparent after several decades of use.

2. Evaluation methods

The broad scope of this study required a suite of mixed methods that included a review of literature, communication via Skype and email with technology manufacturers and researchers in Cameroon, Benin, and Liberia, and ethnographic fieldwork and a series of impact evaluation surveys in Liberia for primary data collection.

The theory of sustainable technology adoption that guided the three projects under study was based on the commercial approach to development, expressed most famously by E.F. Schumacher in *Small is Beautiful* (1973). In essence, local and decentralized manufacture and commercialization of locally viable technologies is assumed to stimulate the growth of small enterprises and local economies. In the case of the Caltech expeller, local metal fabrication shops received training in the manufacture of the machines and received assistance in marketing and commercialization. Donating the expellers as charitable gifts to individuals or groups

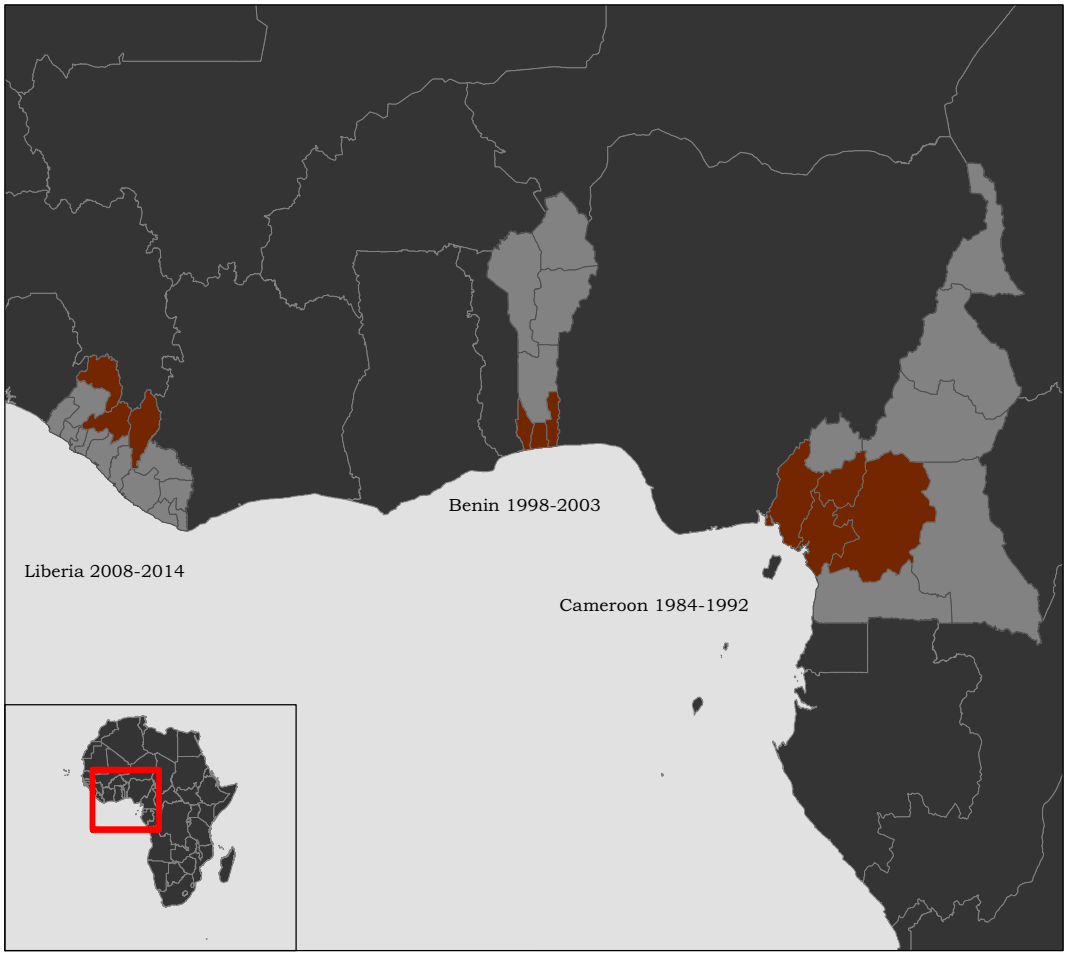

Fig. 2. Map of project Locations and time periods. Source: Will Levin and the author 2011.

Table 1
Overview of three development programs.

	Cameroon	Benin	Liberia	
Project title(s)	Cameroon Oils Project	Benin Oils Project	Liberia Smallholder Oil Palm Revitalization Project (LSOPRP)	Smallholder Oil Palm Support (SHOPS)
Project period	1984–1987	1998–2003	2008–2010	2011–2014
Funding source	USAID/ATI	USAID/Benin	USAID/Liberia	USAID/Liberia
Institutions	ATI	ATI	Winrock	Winrock
	APICA		IITA	ACDI-VOCA
Brand name	Caltech	Dekanmé	Freedom Mill 2	

was understood as antithetical to the goal of creating a sustainable market for the technology. Rather, the projects were based on the premise that if local entrepreneurs and consumers were willing to invest their own capital and resources to purchase a technology because it increased profits or generated savings, then the diffusion would continue without continued project support or subsidies. The Caltech expeller is still being independently manufactured and commercialized in Cameroon, Benin, and Liberia, and therefore this study assumes that the market-based theory of technology diffusion guiding the project strategy in all three cases was in many respects correct.

This study is unique in that the methods used to capture project data, particularly economic data, were very similar across time. The same network of key development professionals were involved in each project and used the same activity implementation strategy and evaluation methods in each case. This consistency in strategy and data collection produced a longitudinal data set that allows for some generalizations to be made across all three projects with regard to numbers of machines sold, outputs, increased income and savings for technology owners and users, and numbers and types of users and businesses involved. However, the goal of this research is not to prove or disprove the sustainability of the market-based approach to development and technology diffusion; rather, the goal is to examine the intended and unintended impacts of technology diffusion over time. The theoretical framework of this study is based on the insights of Anthony Bebbington, who has emphasized the intellectual need to go beyond individual cases of development projects and do much more comparative work across place-based studies in order to build theory upward and elaborate more strategic lessons for theory and practice (Bebbington, 2003). This approach requires general knowledge of transnational development processes as well as attention to the particulars of place.

In addition to economic impact, which was the focus of institutional evaluation research in Cameroon, Benin, and Liberia during the project periods, this study also examines the social,

environmental, and political impacts of technology diffusion both during and after the project periods. The objective of this line of questioning is to analyze long-term technology policy implications in the context of developing countries, particularly with regard to forms of social, environmental, and political change that may complement or possibly conflict with international development policy goals.

2.1. Literature review

To analyze complex cultural, environmental, and political processes and impacts, this research builds on and contributes to scholarship in the fields of social studies of technology (STS) and cultural and political ecology in addition to the interdisciplinary study of development. In tandem with the radical policy shifts occurring in international development in the mid-twentieth century, a large body of academic works emerged focusing on the role of technology in development (Dickson, 1974; Goulet, 1977; Illich, 1973; Jéquier, 1976; Morrison, 1980, 1983; Rosen, 1977; Schumacher, 1973; Stewart, 1972; Thomas, 1979). This literature explicitly interrogated the relationships between technology, politics, and culture and made many suggestions as to how development might be redirected to benefit more people via new forms of technology that would reflect diverse cultural and political values. Researchers pointed out that non-adoption of all forms of technology for development was common and that diffusion was not a linear process (Austen and Headrick, 1983; Barlett, 1980; Blaut, 1987; Gershon, Just, & Zilberman, 1985; Rogers, 1983; Yapa and Mayfield, 1978). The unique contexts in different locations, changing market conditions, and emerging policy environments all played roles in shaping technology diffusion (Feder and Umali, 1993). In a similar vein, critical studies of technology in Africa have demonstrated the complexity of technological diffusion, the non-static nature of technology, and the ways that local populations adopt, accelerate, modify, deploy, reject, and disrupt diffusion processes (Carney, 1996; Crewe and Harrison, 1999; Harding, 2011; Hecht, 2012; Jules-Rosette, 1990; Mavhunga, 2017; Powell, 1995; Wyche, Smyth, Chetty & Aoki, 2010). Overlapping with critical studies of technology a broad body of cultural and political ecology scholarship focuses on development in Africa, particularly the intersection of political economy, agriculture, technology diffusion, and environmental degradation (e.g. Bassett, 2001; Bernstein, 1977; Blaikie, 1985; Bolten, 2009; Brottem and Unruh, 2009; Davis, 2007; Fairhead and Leach, 1995; Leach, 1989; Lundy, 2012; Moseley, Schnurr, & Kerr, 2015; Page, 2003; Richards, 1983; Schroeder, 1999; Watts, 1983). These bodies of scholarship provide an intellectual foundation from which to interrogate relationships between actors and evaluate the social, environmental, and political impacts emerging from small-scale technology diffusion in the African oil palm sector.

The review of literature surrounding the particular technology in question included peer-reviewed, published articles concerning the projects in Cameroon (Hyman, 1988, 1990, 1992; Nchanji et al., 2013; Nkongho et al., 2014) and Benin (Adégbola et al., 2003; Fournier, Adje, and Okounlola-Biaou, 2000; Fournier, Muchnik, & Requier-Desjardins, 2002; Savi et al., 2004). Dr. Hyman's articles regarding the project in Cameroon are all based on primary data collected during project implementation between 1984 and 1992. The other articles were written by researchers in Cameroon and Benin who were not employed or directly associated with the projects. This literature review also included annual, quarterly, and impact reports from the institutions that implemented the projects (USAID, Appropriate Technology International, EnterpriseWorks Worldwide, and Winrock International). While not peer-reviewed, these materials provide explanations of the project strategy deployed across the three projects, anticipated and achieved results figures, and technical information about technology performance, sales, and participation.

2.2. Key informant interviews and ethnographic methods

The lead researcher of this study spoke to and interviewed engineers, agricultural experts, and representatives of nongovernmental organizations in Cameroon, Benin, and Liberia in order to collect information concerning the current state of Caltech manufacturing. Dr. Raymond Nkongho and Yvonne Nchanji of the Center of International Forestry Research provided photographs and explanations of the current use of the Caltech expeller in Cameroon. A technology manufacturer and an agricultural expert who both reside in Cameron provided information on sales trends and the market for the technology in 2014. Dr. Thierry Godjo, a researcher at the University of Abomey-Calavi, explained ongoing technical adjustments being made to the Caltech expeller in Benin by Beninese engineers and fabricators in 2012.

The lead researcher conducted fieldwork in Liberia in June 2011 and January 2013 as the Senior Evaluation Advisor for SHOPS. In addition to the survey research, the lead researcher conducted extended interviews with some of the project participants while visiting their homes, farms, and places of business. Other ethnographic methods were implemented such as "walkabout" tours of oil palm plantations and farms, participant observation of palm oil production, distribution, and marketing activities, and household food purchasing and preparation. Key informants included Caltech manufacturers, oil palm farmers, community leaders, palm oil processors, small business owners, representatives of womens' groups, technology vendors, and project staff.

2.3. Impact surveys

A series of impact surveys and a qualitative baseline study provide the primary data for this research. In June 2010, the lead researcher supervised the final evaluation of LSOPRP in Liberia. A total of 48 technology users were interviewed. Between June 2011 and June 2014, the lead researcher conducted a qualitative baseline study, two midterm evaluations, and a final evaluation for SHOPS. The qualitative baseline study (Bishop and Drobia, 2011) focused on the uses of different varieties of oil palm in Liberia and included interviews with a variety of actors in the oil palm sector. For the SHOPS impact evaluation surveys, different standardized questionnaires were developed for different categories of project participants including technology users. Other project participants surveyed included manufacturers, vendors, and tree nursery operators, however the responses of these participants are not factored into the analysis of this study. For the SHOPS midterm evaluation survey in 2013, the number of technology users surveyed was 61 and for the final evaluation in 2014, 68 technology users were surveyed. The questionnaires for all of the surveys included questions covering the following topics:

- Socio-demographic information
- Employment information
- Income generation information
- Information on previous method of oil production
- Experience with the technology
- Length of time in operation
- Overall level of satisfaction
- Challenges and recommendations

Each questionnaire included several open-ended questions to elicit individual perceptions of the technology diffusion process. The lead researcher also asked local project staff in Liberia to answer a series of qualitative questions about their interpretation

of project impacts and their ideas about potential long-term outcomes. Their responses were used to triangulate the data collected from the project participants and to provide a more nuanced understanding of the social and environmental impacts at local and national scales.[1]

Similar impact evaluations as those implemented in Liberia between 2010 and 2014 were conducted in Cameroon in the 1980 s and in Benin in 2002. These earlier studies serve as secondary sources of data. This research is in part retrospective in its approach, in that no new surveys were conducted in Cameroon and Benin in conjunction with the work in Liberia. To address this gap, the primary data from Liberia is compared to the secondary data and later independent studies of technology adoption in Cameroon and Benin in order to identify trends and points of difference across the three cases.

3. Impacts of diffusion

The social, economic, and environmental impacts of the diffusion of the Caltech expeller between 1984 and 2014 across a large region of western and central Africa are complex, situational, and emergent. The scope of this research is necessarily broad and requires a degree of generalization that could be construed as reductive. Therefore all effort has been made to specify the impacts that are highly localized while presenting data that suggests broader trends. Despite the differences across time and geographic location, the main economic indicators that were consistently tracked in each project allow to for some quantitative data aggregation and comparison. The shared culture of oil palm across the region as a basis of rural livelihoods provides a starting point from which to generalize findings concerning social and environmental impacts derived from qualitative data. Moreover, the political economy of the oil palm in each of the three countries demonstrates similar historical trends with regard to the actions of the global palm oil industry. Pre-colonial, colonial, and contemporary governing bodies in Cameroon, Benin, and Liberia have supported and promoted industrial oil palm plantations and oil processing by attempting to integrate local smallholders into the global supply chain. Many smallholders in all three countries have resisted and redirected such efforts to meet the needs of local economies rather than transnational corporations. This study does not assume that the context of oil palm agriculture and development are identical across the three countries, but rather that overall, the cultural, political, and historical ecology of the region known as the African "oil palm belt" (Sowunmi, 1985) provide a coherent contextual basis from which to generalize some of the findings across all projects.

In each subsection data and findings are analyzed in the case of the technology in Liberia, and then compared to the findings and conclusions of prior studies evaluating the performance and impacts of the technology in Cameroon (Hyman, 1988, 1990, 1992; Nkongho et al., 2014) and Benin (Adégbola et al., 2003; ATI/Benin, 2002; Savi et al., 2004).

3.1. Social impacts

The adoption of the Caltech expeller has altered social relationships in novel ways by enabling technology users to interact, collaborate, and compete with community members and consumers in new and traditional economic activities. Transformations begin with the physical act of processing palm oil and the novel ways people have reorganized their relationships to work with the new technology. In Bong, Lofa, and Nimba counties in Liberia, manual methods of palm oil processing often involve large numbers of community members who may all claim a share of the final product. This form of shared labor constitutes an important community interaction by reinforcing relationships across gender and age groups, reiterating traditional cultural practices such as performing specific oil processing techniques and demonstrating these to younger generations, singing songs while pounding palm fruits, storytelling, joking, and cooking. These types of community interactions are disrupted and altered with the introduction of mechanized extraction.

First, most Caltech owners employ workers thereby establishing new social connections and networks. The expeller owners typically employ various categories of workers to carry out the different phases of production. In some instances, cooperative groups purchased the expellers and delegated responsibilities among members who are also considered "employees" in this analysis. The employees were categorized as managers, clearers, harvesters, and millers/pickers. In 2014 the mean number of employees counted per mill was eight, of which 81% were men and 19% were women. For 480 mills in Liberia, there are an estimated 3840 employees. The employees working for palm oil enterprises and cooperatives generally receive compensation in cash or in kind. On average, managers earn USD 1.92 per day of work, clearers earn USD 1.72, harvesters earn USD 2.38 due to the physical dangers associated with the job, and millers/pickers earn USD 1.75. Many of the workers are paid in gallons of palm oil either instead of or in addition to cash wages.

Each individual Caltech expeller constitutes a site of newly established social relations. Not all of these relations are hierarchical as in the case of technology owners and their employees. In addition to hiring workers to process palm oil, nearly all of the expeller owners (95%) reported that they rent out the expellers as service units to customers. The customers transport fresh palm fruits to the processing site where the machine is located, and pay a service fee in cash or kind to use the technology. According to project records, each unit serves approximately 21 customers. For 480 units, this equals approximately 10,000 customers. Thus the aggregate effects of the diffusion of the expellers in Liberia impact a relatively large population when considering not just the technology manufacturers and owners, but also the processing business employees and the milling service customers. New types of social and economic networks are emerging and growing based on technology adoption leading to diversified livelihood options, employment generation, and interactions between technology owners and customers, and palm oil producers and consumers.

The cash income from processing activities has allowed the technology users to "solve many financial problems," pay for the cost of school fees and medical bills, buy food, build houses, and purchase property. Most of these costs were previously beyond the means of many of the technology users due to the lingering effects of the civil war and Liberia's prior history of rural–urban relations including a lack of infrastructure, goods and services, and stable distribution and circulation of cash money in rural areas. Thus a technology that contributes to increasing the incomes of the rural population has helped to ameliorate these pressing issues by allowing people to earn and spend money on products, services, and social obligations that matter to them.

Although the diffusion of the Caltech expeller has contributed to generating social benefits in Liberia, the commercial approach of the projects based on private ownership of goods and property may exacerbate some forms of social and economic inequalities. In general those who can afford to purchase a Caltech expeller are already in a favorable economic position compared to the majority of farmers and small business owners. The technology owners often have privileged access to capital and raw materials,

[1] Detailed survey methods are presented in Bishop (2014).

allowing them to invest in the machines in the first place. The technology owners also tend to earn higher profits than their employees, or customers, or oil processors using manual methods, and therefore technology owners enjoy greater economic power and prestige. In Liberia, as in Cameroon and Benin, the majority of owners are men.

Men constitute not just the majority of owners, but a substantial portion of workers and customers as well. In 2014, over eighty percent of the employees employed by Caltech expeller owners in Liberia were men. In the case of the Caltech expeller in Benin over a longer period, it is possible that the spread of mechanized processing has contributed to the increasing exclusion of women from the palm oil sector (Fournier et al., 2002). Manual oil processing provides an important livelihood activity for women in Benin. Women do not typically own plantations and farms but rather source raw palm fruits from other producers. When the oil palm producers acquire mechanized oil extraction equipment, the supply of raw materials to women is diminished because the producers keep and add value to the palm fruits themselves (Fournier et al., 2002; Kiki, 2000). This critique however does not take into account the different markets for dura and tenera oils in Benin, and the likelihood that demand for dura palm oil as a staple food would encourage women to continue to engage in manual processing as a livelihood option. Generally speaking in most markets within and bordering the African oil palm belt, customers pay a premium for the manually processed, dura variety of palm oil because of a preference for its consistency and flavor.

Another important gendered socio-economic change triggered by the circulation of the Caltech expeller is the transformation in rules surrounding the ownership of the palm kernels, a byproduct of oil extraction and a potential source of use and exchange values. For example, traditional ownership rules in Liberia allowed the person who supplied the palm fruits – typically women – to keep the kernels. However, it is difficult for women to add value to the kernels due to the labor involved in the process. Manually cracking palm kernels typically entails using a rock to crack open the hard shells and extract the kernels, and it is a slow process. Despite the labor constraints women claimed the value of the kernels, whether or not they chose to exploit it. However with the introduction of the Caltech expeller and kernel-cracking machines, and increased local production of kernel oil and animal feed, the demand for kernels has grown and oil processors encourage children and family members to collect and sell kernels to local buyers. The ownership rules surrounding access to palm kernels are changing with the advent of the mechanization of palm oil extraction, with repercussions for women's livelihoods. Instead of the palm fruit supplier claiming the kernels, they now belong to the technology owners and/or the owners of the palm oil processing site. This new system of ownership emerged in Liberia with the introduction of the expeller. This may be due in part to the problem of removing the kernels from the fibrous byproduct of processing with the machines, which is quite labor intensive and time-consuming. Most women processors transport their palm fruits to a processing site rather than performing the work at home or on a family farm, and do not want to have to spend the extra time removing kernels from the fibers at a distant location.

The changes in kernel ownership rules removes potential value from the control of women in most instances and places it in the hands of the technology owners, who are mainly men. As the demand for kernels increases, the opportunities for women to claim ownership of the kernels are decreasing. Thus the circulation of the technology has led to a gendered opportunity cost with implications for women's livelihood options. Many women in Liberia have accepted this cost for now, however, in exchange for labor reduction in palm oil processing.

3.2. Economic impacts in Liberia

In Liberia, two types of red palm oil are produced and exchanged within local market networks. The first type, the oil of the dura variety of oil palm, is commonly used as a cooking staple. Like in other parts of West Africa, dura oil is continuously in high demand in Liberian markets and is generally available wherever food staples and condiments are being sold. The second type, the oil of the tenera variety of oil palm, is used for soap making and traded to exporters. Once oil has been processed, it is either sold to a middleman or sold directly to an oil depot in a central market. Operators at the depot store large quantities of palm oil in warehouses and sell oil in bulk to wholesalers. Wholesalers resell palm oil to smaller retailers, who then sell the product to consumers.

The palm oil market has existed for centuries in West Africa, and it continues to supply important economic returns to both producers and retailers. In many locations throughout the oil palm belt women have historically controlled local palm oil trade (see for example Ay, 1990; Hofstra, 1937; Kiki, 2000; Leach, 1989; Martin, 1984, 1988). This trend in the gendered division of labor continues to dominate relationships and processes in domestic and subregional markets in Cameroon, Benin, and Liberia (Fournier et al., 2000; Nchanji et al., 2013). Women also control trade in palm kernels and palm kernel oil. In Liberia, women work at markets in Gbarnga, Zorzor and Monrovia, as well as small stands along the main road linking these towns. At the oil depot in Gbarnga, the women pay a small fee per week (around USD 0.30) to buy, sell, and store palm oil in a large warehouse.

The Liberian Marketing Association instituted a policy meant to bypass middlemen in palm oil sales in order to reduce conflict between producers and retailers by stabilizing oil prices. In Gbarnga, for example, the producers bring the palm oil to the oil depot and receive a standard price per gallon. The palm oil is measured in gallons and stored in five-gallon tins, then resold. The prices increase as the palm oil becomes scarce in October and November. This lucrative trade in palm oil supplies income to a large number of collectors, retailers, and oil processors. Technology to increase palm oil production has therefore generated widespread interest in rural areas.

According to the SHOPS final evaluation (Bishop, 2014), to acquire a Caltech expeller, 60% of the owners had used their own money. Far fewer had obtained loans from a credit union (8%) or bank (3%). Three percent had received money from family or friends to make the purchase. These purchases provide evidence that consumers are investing money in the expellers, suggesting that they will continue engaging in technology use with or with assistance from a development project. Notably, 20% of the owners reported that NGOs had given them the equipment or funds to buy it. This finding suggests that the commercial approach of the project was compromised by the activities of other NGOs, since the charitable donation of equipment to the owners is perpetuating the "hand out" model of development that conflicted with the market-based strategy of LSOPRP and SHOPS. If potential consumers expect to receive the expellers as donations, then they will be much less inclined to invest their own money to acquire them. This can skew the market for the expellers, and it can ultimately hurt the technology manufactures whose client base disappears when NGO activities end. On the other hand, the donated expellers may have been beneficial in marketing the technology to other potential buyers in more remote areas. And despite the strategic error in terms of diffusion, women and women's cooperatives could benefit greatly from receiving the machines as charitable donations since they are much less likely than men to have access to and control over the capital needed to purchase equipment.

By far the most common variety of palm fruit processed in the mills is tenera (median 95%) rather than dura (median 5%).

Although a few owners reported processing between 60% and 90% dura palm fruits the majority of owners were processing tenera most of the time. The preference to process tenera reflects the perception and experiences of the technology users that the expeller operates more efficiently using tenera rather than dura. In Benin and Cameroon, the technology users expressed similar perceptions concerning the performance of the expeller (Hyman, 1990; Savi et al., 2004). In addition, in Benin the "table quality" of dura oil is perceived to be compromised when extracted mechanically (Fournier et al., 2002; Savi et al., 2004). In Cameroon, one researcher has indicated that farmers cultivate both varieties of oil palm and dura oil tends to sell for a higher price, thus the users have therefore tried to adapt expellers to work with the two varieties.

The owners operated the expellers for a mean period of six months per year. During those six months, the owners reported that they worked a mean of six hours per day, four days per week, or 24 h per week. The estimate of six hours worked per day excludes the "downtime" during periods of resting, preparing the palm fruits, and switching between operators that happen in between periods of active palm oil pressing. With an average of 16.8 days of operation per month, the total number of days of operation per mill per year is 101, or a total of 606 h per year. The owners reported that one fifty-gallon drum of palm fruits can be processed in 40 min to produce 2.88 tins (5 gallons) of crude palm oil. This results in an average output of 21.6 gallons of palm oil per hour. For 606 h of operation, this equals an output of 13,090 gallons of oil annually per machine. For 480 expellers, this amounts to more than six million gallons of oil processed per year. As noted above, oil from tenera fruits constitutes approximately 95% of the total amount of oil processed. At an average value of USD 2.58 per gallon as of March 2014, the total amount of tenera oil produced was worth over USD 15 million. The palm oil produced from dura fruits has substantially higher value of USD 2.94 for a value of nearly USD 924,000 for 5% of the total number of gallons produced (Table 2).

To use the mill services, 93% of the customers paid in gallons of palm oil. While only one customer stated that the payment was four gallons of oil per drum of fruits, all of the other customers paid between one and two gallons of oil per drum of fruits processed. In Bong and Lofa counties, the customers paid two gallons per drum while in Nimba County, most people paid one gallon of oil per drum of fruit processed. This spatial grouping reveals dissimilar economic and cultural norms shaping owner-customer relationships pertaining to palm oil businesses in different regions of Liberia.

Prior to the introduction of the technology, all of the customers interviewed stated that they produced palm oil manually. Manually processing one drum of palm fruits took on average eight hours. When using the expeller, the time to process one drum of palm fruits is reduced to approximately 42 min. Mechanical processing takes only 9% of the time needed for manual processing. The saved time is generally used to prepare an increased amount of palm fruits to process or is spent on other activities. When asked why they chose to use the technology, most customers (93%) said that it required less work than the manual method. Ninety percent also reported that the quality of oil produced was better, and 40% noted that the use of the expellers reduced production costs. Thus the reduction in labor time and effort and the improved oil quality were considered the most beneficial aspects of the technology. Only 10% of the customers stated that they also continue to produce palm oil manually. Several noted that they still use the "pit" method to make dura oil and they also use the pits when the expeller is not available.

The guiding logic of the project in Liberia promoting the Caltech expeller claims that the technology creates an economic "win–win" scenario for both the technology manufacturers and the users. This claim is supported by the data analyzed in this study. The manufacturers earn income from the profit margins of expeller sales, and the technology users increase their incomes from oil processing. The mutually beneficial processes and interactions between producers and consumers constituting the diffusion of the expellers contributes to its high degree of economic sustainability, understood as the unsubsidized perpetuation of the economic activities based on the technology.

3.3. Environmental impacts

The environmental impacts of the Caltech expeller may be broadly categorized into the following dimensions: water use, tree crops production, and public health and nutrition. In Liberia, the Caltech expeller reduces the amount of water needed to process each batch of palm oil. For example, the manual method of oil extraction requires up to five drums of water per drum of palm fruits processed while the use of the Caltech expeller requires only half a drum. However, the total amount of wastewater produced may ultimately stay the same or increase due to the overall increase in processing activities. Even though less water is used per gallon of oil, a far greater number of gallons are being processed. Individual users may perceive a reduction in water usage, but the aggregate use across all technology users is greater than before the introduction of the technology.

The wastewater from processing activities is generally directed into streams. The amount of wastewater produced using manual methods does not generally accumulate or cause lasting damage to river ecosystems. Manual processing methods are labor intensive and therefore total palm oil outputs per day are necessarily limited. However, once oil extraction activities are scaled up through mechanization, more wastewater is produced and

Table 2
Value and amounts of tenera and dura oils processed in 2014 using the Caltech expeller in Liberia (Bishop, 2014).

	Tenera	Dura	All
Percent of output	95%	5%	100%
Annual output for 480 expellers (gallons)	5,969,040	314,160	6,283,200
Value (per gallon)	USD 2.58	USD 2.94	
Total value	USD 15,400,123	USD 923,630	USD 16,323,753

Fig. 3. Wastewater from small-scale palm oil extraction can pollute streams and rivers. The amount of pollution increases as people use technology and increase extraction activities. Source: Author 2011.

Fig. 4. In addition to technology promotion, the SHOPS project trained Liberian nursery operators to propagate and commercialize hybrid tenera seedlings. Source: Author 2013.

released into the environment (Fig. 3). In Cameroon, the wide diffusion of mechanized expellers over time has contributed to increasing pollution in streams and rivers (Nchanji et al., 2013; Nkongho et al., 2014). This does not yet seem to be a noticeable issue in Liberia, although certainly the continuing diffusion of the expellers could trigger similar processes. Finding other uses for the wastewater could mitigate the negative environmental impacts of artisanal palm oil production.

In addition to promoting the expeller to farmers and entrepreneurs, the SHOPS project also trained Liberian nursery operators in the propagation and commercialization of tenera seedlings as was the case in the previous project in Benin (Fig. 4). The strategy was to provide farmers with locally sourced planting materials. The final evaluation of SHOPS provided insights into the relationship between oil palm production and technology usage in Liberia (Bishop, 2014). Approximately 66% of the expeller owners in Liberia operated the machines on small plantations with varying proportions of dura and tenera palms. The reported areas harvested ranged from two to 96 ha. The farm covering 96 ha was a major outlier, however, with the next largest farm measuring 13 ha. The median area harvested was 2.5 ha. For all technology owners the estimated area harvested for local processing activities using the Caltech expellers was nearly 800 ha. This does not take into account the areas harvested by the technology customers, which would substantially increase this figure. The harvested areas represent farms and small plantations that are benefitting from rehabilitation after long periods of neglect and decline. One cooperative member explained that he and other community members planted oil palms throughout the period of the civil war in anticipation of the resumption of economic activities when the war would finally end. In between periods of combat, fleeing, and hiding, some rural producers were able to continue working. In general, however, tree crops production was severely hindered during the war. The rehabilitation and establishment of small plantations is perceived as an environmental benefit. One of the major challenges of oil palm farming in all three project contexts was the lack of processing capacity and the resulting wastage of raw palm fruits (Savi et al., 2004; Hyman, 1990).

Tenera is often farmed as a monoculture, although the small scale of the local farms in Liberia reduces much of the threat of negative environmental impacts. However, industrial monoculture of oil palm has contributed to serious environmental degradation, habitat destruction, and loss of biodiversity in the tropical regions of the world, particularly in Indonesia and Malaysia and in some parts of Africa. In Cameroon, land acquisition by a U.S.-owned palm oil corporation has erupted into a political conflict between local communities, NGOs, and the Cameroonian government (Hoyle and Levang, 2012; Ndi and Batterbury, 2017; Teclaire and Geenen, 2015). The negative environmental impacts of oil palm development are linked to global processes of capitalism and the common (and often unethical) practices of land grabbing, profit-oriented monoculture, and externalization of extraction and production costs such as the displacement of communities, reduction of biodiversity, impacts of herbicide, pesticide, and fungicides, loss of soil fertility, and release of factory waste. The diffusion of Caltech expellers does not directly contribute to these types of environmental impacts because it is mainly smallholder farmers who are buying and using the machines, not industrial plantations. The smaller plot sizes, practice of polyculture, and relative lack of access to agricultural chemicals results in much less severe environmental impacts on small farms producing dura and tenera palm fruits for processing. For example, Cameroonian and Liberian farmers have tended to intercrop tenera with dura oil palms, yams, rice, and other food and tree crops thereby diversifying production and offsetting potential problems associated with monocultures (Cheyns and Rafflegeau, 2005). If small-scale tenera production continues to increase economic benefits for farmers in Cameroon, Benin, and Liberia, a broad shift toward tenera monoculture could trigger greater environmental impacts over the long-term by reducing biodiversity and exhausting soils. This is unlikely in the near term, given the need and preference of most smallholders for diversification.

Not just production, but consumption of palm oil may contribute to environmental impacts. Over the long term, processing technologies and the introduction of tenera farming could lead to changes in local patterns of consumption particularly with regard to palm oil as a staple food. Thus far, this has not occurred in any of the project locations. Despite its higher price, consumers in Cameroon, Benin, and Liberia have not abandoned dura palm oil as the preferred cooking oil. However, as more tenera palm oil is processed and circulated in local markets, decreasing prices may compel some people to switch to the lower-cost option. This transition could potentially have implications for nutrition and public health linked to the differing proportions of free fatty acids in the different varieties of palm oil. For now, tenera is likely to remain the oil of choice for soap making and exchange while dura will continue to be used as the preferred edible oil.

3.4. Political impacts

A recent study of artisanal palm oil milling in Cameroon found that while small-scale technologies such as the Caltech expeller are not as efficient as industrial technologies, many small producers prefer making their own oil because it is more lucrative (Nkongho, Feintrenie, & Levang, 2013; Nkongho et al., 2014). During the low season, artisanal producers can earn higher profits by making and selling their own oil rather than selling fresh fruit bunches at a set price to the industrial plantations. This situation is highly unfavorable from the perspective of the large plantations, however.

> Officials in the Ministry of Agriculture and Rural Development consider artisanal milling as a huge waste because of its low extraction efficiency compared to industrial mills. Agro-industrial companies must temporarily close down their mills during the low production season due to the absence of FFB [fresh fruit bunches] from smallholders, which usually complement FFB from the estate. Last but not least, such companies consider that a large proportion of the FFB processed in artisanal mills is stolen from their estates. Thus, plantation companies regularly ask the Government to close down artisanal mills, at least those which are close to estates. (Nkongho et al., 2014: 1587).

Although the Caltech expeller was designed as a profit-making technology and diffused through a market-based development approach, it has not received favorable attention from other private-sector actors, particularly those managing large, corporate plantations. The Caltech expeller undermines the activities of large plantations by creating economic opportunities in marginalized rural areas and drawing potential laborers away from seasonal employment.

In Liberia, government officials and powerful actors in the palm oil industry have preferred to refer to the Caltech expeller as not an "appropriate" or "intermediate" technology but rather a "transitional" technology. The use of the term transitional denotes a process of change in the manner in which palm oil is produced at the sub-industrial scale. The people who call the Caltech expeller a "transitional" technology assume that it will be in use for a specific amount of time – a period bridging the practice of manual palm oil processing and the enrollment of Liberian producers into transnational palm oil production networks based on large plantations. The underlying message is that artisanal palm oil processing is, or really should be, an intermediary step in the linear process of economic development. The process should terminate only when the manual and artisanal methods of production have been phased out in favor of industrial scale operations that are more efficient.

From the perspective of the technology users, efficiency and profitability have a different meaning. The goal of most oil processors is to realize a profit but there is less emphasis on the need to increase profits over time, a fundamental assumption in classical economics. There is no likelihood that a processor using a Caltech expeller would eventually grow the business to be competitive with an industrial plantation. Rather, small producers are operating under a different logic emphasizing livelihood diversification based on the goals of family self-sufficiency, adaptation to local markets, and buffering against potential loss (Batterbury, 2001; Bernstein, 1977; Cheyns and Rafflegeau, 2005). This is what makes the technology unfavorable to corporate interests. The adoption of the technology allows the users to create alternative economic relations that do not rely on global capital flows but rather stimulate local and regional market activities. Caltech owners and customers are difficult to enroll in global economic circuits as laborers or consumers of industrially produced palm oil.

Ideologically, the Caltech expeller was not designed to insert or connect local producers into transnational production processes. With regard to the dominant global economy, the technology was conceived as an alternative, not complementary, means of production. The radical nature of the Caltech expeller as an appropriate technology

> ...is aimed at reducing dependency on foreign corporations. This is easier said than done, because these corporations usually have strong bargaining positions in the economics of Third World countries, especially in terms of the production of cash crops. (Treurnicht and Treurnicht, 1991:73)

The Caltech expeller and other small-scale extraction units not only reduce dependency on corporations but also constitute a direct threat by capturing local palm oil markets.

The technologies help local producers to compete with, and in some respects circumvent, the insertion of transnational palm oil corporations into rural communities. The technology was intended to create and contribute to a process of economic decentralization, although it was imagined to do so in a context where national governments would promote the interests of small farmers over the demands of big business. This assumption has been proven false in most instances. In Cameroon, the threat of competition and the destabilization of dominant economic processes have prompted palm oil corporations to influence national politics to the extent that the government may ban small scale oil expellers (Evans, 2014; Nkongho et al., 2014; Schneider and Collins, 2015) (Fig. 5).

Fig. 5. Palm oil millers in Cameroon use a vertical Caltech expeller in 2013, nearly 30 years after the technology was introduced. Source: Patrice Levang, CIFOR/IRD 2013.

4. Conclusion

This post project evaluation was designed to capture and reveal complex social, economic, and environmental impacts linked to the diffusion of technology for development in Africa. Rather than limiting study parameters to the duration of a single project, this study used an expanded conceptual framework to integrate data and findings across a series of three projects promoting the Caltech expeller, in three countries, over a period of thirty years. This study confirms that comparative, longitudinal evaluation research can reveal important impacts of technological change that are not always apparent within the immediate project period or even within a few years of project termination. Rather the more profound impacts of adoption and diffusion on societies and environments emerge over decades, long after the original development priorities and policies have shifted to new concerns and areas of focus.

As the processes of diffusion have matured, technology diffusion in the palm oil sector has contributed to myriad social, economic, and environmental impacts both intended and unintended. During the initial project phase in which the Caltech expeller was introduced in Cameroon, then Benin, then Liberia, tangible economic impacts were quickly discernable. In all three countries the local manufacture and use of the expeller contributed to increased incomes for metal fabricators, small business owners, and farmers. Technology diffusion offered new or enhanced employment opportunities, improved productivity, resulted in less palm fruit wastage, increased market activity, and contributed to livelihood diversification. As the economic benefits grew, more manufacturers became involved and more customers purchased Caltech expellers, driving geographic diffusion.

The short-term economic benefits of technology adoption led to transformations in the social relations of production between farmers, technology owners, laborers, and traditional owners of oil palm tree and fruits. In the medium-term – that is, towards the end of the projects or after their termination – the social impacts of diffusion became more apparent. Shifting relations of production tended to favor men over women with regard to technology ownership. The likelihood that men were more likely to own the expellers was anticipated in project planning, however the role of the technology in exacerbating gender inequalities in multiple dimensions was not fully understood. While in Benin

men have taken over processing activities that have traditionally been associated with women, in Liberia ownership of palm kernels shifted from women to Caltech expellers owners in certain cases. This represented an opportunity cost in the form of the value of the kernels, their oil, and potential kernel cake and other byproducts that could be made from them. With few alternatives, women have in general accepted the opportunity costs associated with expeller use and benefit from greatly reduced labor requirements in oil processing.

Perhaps the most important, and unintended, impact of the long-term diffusion of the Caltech expeller is the political repercussions facing technology users in Cameroon. By bolstering the autonomy of small producers and allowing them to circumvent dominant processes of development in the oil palm sector, the technology has become a flashpoint of government and corporate retaliation. Official references to the expeller as a "transitional" technology in Liberia hint that a similar fate for the Caltech may be in store there as well. The seeming simplicity of the technology belies the complex nature of the impacts of short, medium, and long-term diffusion over a wide geographic area. Despite unintended consequences that have emerged over time and space, the Caltech expeller has demonstrated a high degree of social, economic, and environmental sustainability that may serve as a model and a source of lessons learned for future development efforts aimed at supporting small producers in Africa. Importantly, this study also reveals the critical role of project evaluation in identifying and analyzing points of political conflict relating to development policies and projects. No longer perpetuating the "anti-politics machine" (Ferguson, 1990), evaluation research must take into account the political context shaping the needs, abilities, and aspirations of technology users in order to mitigate potential social and environmental conflict.

Conflict of interest statement

The author was employed by two nongovernmental organizations that implemented the projects evaluated in this manuscript. From 2001 through 2005, Dr. Bishop was employed as a Program Evaluation Officer for EnterpriseWorks Worldwide where she was responsible for collecting impact data for the Benin Oils Project but was not directly employed on the staff of that project. From 2010 to 2014, Dr. Bishop worked as an evaluation consultant for Winrock International, the organization that implemented the Liberia Smallholder Oil Palm Revitalization Project (LSOPRP) and Smallholder Oil Palm Support (SHOPS). The main contractor for LSOPRP, the International Institute for Tropical Agriculture, and the main contractor for SHOPS, ACDI-VOCA, provided Dr. Bishop with permission to publish research findings related to the projects. Dr. Bishop believes that there is not and will not be any financial or non-financial conflict of interest related to the publication of this manuscript.

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