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Give Someone a Fishpond – Modeling the Impacts of Aquaculture in the Rural Economy

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Abstract:

The rapid growth of fish farming over the past three decades has generated heated debates over the place of aquaculture in rural development. Central to these debates is the question of whether and how aquaculture impacts local incomes and employment, yet little empirical evidence exists on the issue. To address this question, we propose a Local Economy-wide Impact Evaluation (LEWIE) model which nests fish farm models within a general-equilibrium model of their local economy. The model is calibrated using primary data collected from 1102 households in Myanmar’s main aquaculture zone, representative of 60% of the country’s aquaculture. Using this model, we examine the impact of aquaculture on the incomes and labor market outcomes of fish farming households, but also crop farms and non-farm households in the cluster. Simulating one-acre increases in pond/plot surface we find that: (1) aquaculture generates much higher incomes per-acre than agriculture; (2) aquaculture generates larger income spillovers than agriculture for non-farm households, by way of retail and labor markets; (3) small commercial fish farms generate greater spillovers than large fish farms. These results bolster the notion that fish-farming, notably small-scale commercial aquaculture, may have a significant role to play in rural development and poverty reduction.

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Abstract: The rapid growth of fish farming worldwide has recently led to increased awareness of aquaculture's centrality in addressing the global food, economic, and environmental challenges of our time. This has stimulated a heated debate over the role of aquaculture in rural development, central to which is the question of whether and how aquaculture impacts local economies. To address this, we propose a Local Economy-wide Impact Evaluation (LEWIE) model, calibrated using representative household survey data from Myanmar's main fish farming zone. We find that: (1) aquaculture generates much higher incomes per-acre than agriculture; (2) aquaculture generates larger income spillovers than agriculture for non-farm households, by way of retail and labor markets; (3) small fish farms generate greater spillovers than large fish farms.

Keywords: Spillover, local economy, rural growth linkages, land, fish farming, Myanmar/Burma.

Give Someone a Fishpond – Modeling the Impacts of Aquaculture in the Rural Economy

*“Give someone a fish, and you feed them for a day.
Give them a fishpond, and you may generate income spillovers for the whole village.”*

LEWIE proverb

1 Intro

Aquaculture (fish farming) has been the world’s most rapidly growing food production subsector for the past three decades, and now generates more than half the fish destined for direct human consumption (FAO, 2016). The aquaculture sector’s rise to global significance has seen an explosion of interest its potential to stimulate economic growth and reduce poverty in developing countries, where most fish farming is concentrated. However, the literature lacks either a consistent theoretical framework, or a compelling body of empirical evidence evaluating the contributions of aquaculture to rural economic development (Arthur, Béné, Leschen, & Little, 2013; Béné et al., 2016). This article addresses this knowledge gap.

Two main ‘strands’ are evident in the literature linking aquaculture with poverty reduction. We call the first the “small-scale” narrative. This emphasizes the direct benefits that resource poor farming households may gain by producing of fish for home consumption using simple low input technologies, and selling any surplus to earn supplemental income. This narrative is present in the earliest work linking aquaculture and poverty (eg. Ahmed & Lorica, 2002; Edwards, 1999; Edwards, Little, & Demaine, 2002). It has been the dominant theme in the literature since this time (eg. Bondad-Reantaso, M.G. Subasinghe, 2013) and continues to be widely espoused (eg. Golden et al., 2016).

We label the second strand the “SME” (Small-and-Medium Enterprise) narrative. This diverges from the small-scale narrative on two empirical observations: (1) aquaculture’s rapid growth in Asia (and more recently Africa) has been driven overwhelmingly by the investments of commercially oriented farmers and supporting off-farm enterprises, employing a mix of capital intensive, productive, and increasingly sophisticated technologies (Ben Belton & Little, 2011; Brummett, Gockowski, Pouomogne, & Muir, 2011; Hernandez et al., 2017); (2) the poorest households in communities where fish farming occurs rarely have sufficient resources to participate in aquaculture directly as producers, but are able to obtain benefit from the sector through employment linkages (Belton, Little & Haque, 2012).

Unlike the small-scale aquaculture literature, which emphasizes the direct benefits derived from small-scale, semi-subsistence fish farming by producers, the SME narrative infers that a large share of aquaculture’s contributions to poverty reduction are indirect, resulting from employment and business opportunities created both on- and off-farm. Though not always explicitly framed in such terms, the SME

narrative reflects the idea (well-established in agricultural and development economics), that rural growth linkages are a key mechanism by which poverty is reduced (Haggblade & Hazell, 1989; Mellor, 1986).

Growth linkages occur when growth in one segment of the economy generates spillovers to other segments via the interconnectedness of production, consumption, and employment markets, in what Dorward et al (2003) refer to as a 'virtuous circle'. In the context of agriculture, spillovers happen when profits or wages earned from farming or related work are spent on productive investments or consumption. This creates demand for additional goods, services and labor, which in turn create further cascading demand for goods, services and labor.

For instance, farms often demand services and intermediate inputs produced by non-farm enterprises ('production linkages'). In addition to generating income for the enterprises themselves, the growth of these enterprises can provide employment and income-earning opportunities for the poor (Haggblade & Hazell, 1989). Similarly, demand created when farm households or workers spend profits and incomes on consumption goods (food, clothing, transport, leisure activities, etc.) creates 'consumption linkages'. These linkages tend to strengthen as agricultural income grows (Haggblade, Hazell, & Dorosh, 2007).

Households operating small to medium-sized farms have favorable expenditure patterns for promoting growth in the local non-farm economy because they typically spend higher shares of incremental income gained on locally produced 'non-tradable' goods and labor-intensive services than large farms (Diao, Hazell, & Thurlow, 2010). Commercially oriented forms of aquaculture often require significant inputs of labor and other production inputs and are capable of generating much higher returns than staple crops such as rice (Ben Belton, Ahmed, & Murshed-e-Jahan, 2015). Together, these facts suggest that small- and medium-scale commercial aquaculture has the potential to create denser rural growth linkages than either traditional crop agriculture or large scale aquaculture. This hypothesis informs all subsequent analysis in this paper.

A handful of previous studies have attempted to analyze indicators of the extent and size of production, consumption and employment linkages associated with aquaculture. Taken together, their results suggest the following points: (1) The indirect poverty impacts of aquaculture tend to be larger than the direct impacts (Ben Belton, Haque, & Little, 2012; Kassam & Dorward, 2017); (2) Commercial aquaculture can create employment linkages that are greater than those associated with crop farming (B. Belton et al., 2017; Ben Belton et al., 2015), and these employment linkages can be poverty and income inequality reducing (Irz, Stevenson, Tanoy, Villarante, & Morissens, 2007); (3) Small commercial fish farms may create larger multipliers of all types than small non-commercial or large commercial farms (Ben Belton et al., 2012; Kassam & Dorward, 2017).¹

However, with the exception of Irz *et al* (2007) these findings are primarily indicative. The comparability and generalizability of these studies is also limited by their deployment of varied methodologies, limitations in the size, representativeness and quality in the data utilized, the context specificity of the cases selected, and differences in the way in which growth linkages are conceived, evaluated or inferred in each case. Béné *et al.* (2016) provide a similar critique of the broader literature linking aquaculture and

¹ Stanley (2003) presents evidence suggesting that export-oriented aquaculture may generate relatively small backward production linkages and large forward production linkages, though this is beyond the scope of our analysis in this paper

poverty reduction. As Alison notes (2011), “there is little direct quantitative evidence of the size of growth-multiplier effects from fisheries and aquaculture development” – this article provides some.

The present paper makes a methodological and empirical contribution to the literature by modelling production, consumption and employment linkages within the boundaries of a clearly defined rural economy in Myanmar, using a large dataset (n=1102) collected specifically for this purpose and statistically representative of nearly half of all aquaculture ponds in Myanmar (42%). We construct a local economy-wide impact evaluation (LEWIE) model of the areas surveyed, delineating how fish farms and crop farms interact with each other and with other local economic actors (Taylor, 2013; Thome, Filipski, Kagin, Taylor, & Davis, 2013). We use the model to perform simulations that evaluate the full economic contributions of crop farms and fish farms of different sizes. This approach allows us to: (1) quantify growth linkages associated with aquaculture, and compare these with linkages created by crop agriculture; (2) analyze differences in the size and type of linkages created by small-scale and large-scale aquaculture farms, and; (3) assess shifts in income (in)equality associated with the growth of each of these activities.

By simulating a one-acre increase in the land (or pond) holdings of different types of household, we find that aquaculture: (1) produces higher overall incomes than agriculture on a per-acre basis; (2) generates higher income spillovers in the local economy. We also find that small fish farms (under 10 acres) generate higher spillovers than large fish farms, and that an increase in small fish farm area reduces local income inequality, while large farm growth raises inequality. These findings highlight the importance of using an economy-wide lens when examining the role of fish-farms in rural development and poverty reduction. They resonate strongly with the SME narrative on aquaculture development.

In addition, these findings contribute to ongoing policy debates in Myanmar itself. Myanmar’s agricultural policy has historically favored the establishment of very large fish farms by granting land concessions. At the same time, strict regulations governing agricultural land use have slowed smallholder-led fish farm development. As a result, the majority of farm area and output in Myanmar is concentrated among large farms (Belton, Hein, Htoo, Kham, Phyo & Reardon, 2017). Shifting policy priorities following Myanmar’s democratization in 2016 mean that agricultural diversification beyond the staple rice is now encouraged, but restrictions on the conversion of agricultural land to fish ponds remain in place for now. Our finding that aquaculture creates much greater spillovers than crop farming, and that small-scale aquaculture creates more favorable spillovers than large-scale aquaculture, thus has important implications for agricultural policy and the future of aquaculture development in Myanmar.

The remainder of the paper is organized as follows. The following section provides context on the characteristics of Myanmar’s aquaculture sector. Section three describes the survey methodology, data and model specifications. Section four presents model results on the size and nature of growth linkages associated with large and small-scale commercial aquaculture and crop farming. Section five concludes by evaluating implications for the literature on aquaculture and poverty, and agricultural policy in Myanmar.

2 Background: Aquaculture in Myanmar

Aquaculture has grown rapidly in Myanmar over the last two decades and plays an increasingly important role in national fish supply (Belton et al., 2015). Fish farms are highly concentrated in the delta of the Ayeyarwady River, close to the former capital city of Yangon, where there are an estimated 235,000 acres of fish ponds (*ibid*).

Unusually for an Asian country, the ownership structure of fish farms in Myanmar is highly concentrated. Belton, Hein, Htoo, Kham, Phyo & Reardon (2017) estimate that half of all fish farms are sized under 10 acres, but that these make up only 4% of pond area. In contrast, farms of 100 acres and above account for 6% of farms, but 60% of pond area. Our own survey of fish farming households returns similar results.

The predominance of large fish farms is closely linked to Myanmar's agricultural land use policy history. From 1989, when the military government of the State Law and Order Restoration Council seized control of the country, large scale fish farming was promoted as part of a wider policy to encourage industrial-scale agriculture. Large areas of untitled land (including land previously worked by paddy farmers without formal tenure) were allocated to large investors in what are now the main fish farming areas. The growth of small and medium fish farms has also been impeded, though not prevented, by land tenure regulations and policies intended to safeguard national self-sufficiency in rice production. These regulations mean that formal permission to convert agricultural land into ponds is difficult to obtain, and usually involves the payment of substantial bribes (Belton et al., 2015).

The tension between: (1) state mandated use of land for smallholder paddy cultivation - the performance of which is among the worst in Asia, by any measure of productivity (World Bank 2016); (2) state prohibition of smallholder conversion of paddy land into potentially much higher return aquaculture, and; (3) state promotion of industrial scale fish farm development, forms the crux of this paper in policy terms.

As Myanmar enters a new era of democratic government, calls for agricultural policy reform frame the promotion of smallholder-led agricultural diversification into high value crops (including fish) as a motor for rural growth (e.g. NEASC, 2016). However, these views are tempered in some quarters of government by a narrative that equates food security with paddy production. The question of how competing uses of agricultural land perform in terms of local economy-wide impacts is thus one of critical practical relevance.

3 Data and Methods

3.1 MAAS survey and Data collection

All data used in this study originates from a household survey - the Myanmar Aquaculture-Agriculture Survey (MAAS) - implemented in May 2016. MAAS was designed to meet two objectives: (1) Generate a baseline of information on fish and paddy farm yields, size structure, tenure status, crop management practices, and profitability; (2) Quantify relative advantages of, and tradeoffs between, aquaculture and agriculture by estimating the size of spillovers in the local rural economy.

Aquaculture in Myanmar is heavily concentrated in three regions (Ayeyarwady, Yangon and Bago), home to 90% of the country's fish pond area (DOF, 2014). Most of these ponds are located close to the country's largest city (Yangon). A two-stage sampling procedure was adopted to gather data from groups of village tracts with high concentrations of fish farms.²

For first stage sampling, satellite images from Google Earth were analyzed to pinpoint all inland fish ponds in Ayeyarwady, Yangon and Bago. Ponds were identified through a systematic manual search of high resolution images and tagged digitally to generate a database of pond boundaries and locations. After crosschecking for validation, ponds retained in the database were mapped using Arc-GIS software. The identified ponds are shown in Figure 1. Pond area and density (pond area divided by total land area) were

² Village tracts are the smallest administrative units in rural Myanmar, usually comprised of around 10 villages.

estimated using Arc-GIS in every village tract where ponds were identified. The 25 village tracts estimated to have the highest densities of ponds were selected for survey. These village tracts were spread across four townships within a 60 km radius of Yangon. Together, they form what we refer to as the aquaculture cluster, depicted in Figure 1.³ Overall, the village tracts selected for survey contained 42% of the total area of inland fish ponds in the country.⁴

For second stage sampling, enumeration areas (EAs) were selected from the 25 aquaculture cluster village tracts by probability proportional to size, using the national population census of 2014 as the sampling frame. This procedure yielded a sample of 49 EAs. A census of households was conducted in every selected EA to serve as the final sample frame for randomized selection of respondent households.

The sample was designed to represent the entire population of the aquaculture cluster, including fish farming, crop farming and landless households, to facilitate estimation of spillovers from aquaculture and agriculture. Eight fish farming households and seven non-fish farming households were interviewed in each EA. Non-fish farming households included both crop farmers and those engaged exclusively in non-farm employment. Households operating fish farms of 40 acres or more were selected with 100% probability to ensure a sufficient sample of large farms to support statistically valid analysis. Survey weights were applied during analysis to correct for the effects of the sample design.

Respondents from 685 households, representing a total population of about 29,087 households, were interviewed one on one in the privacy of their own homes. A total of 242 fish farming households were surveyed in the aquaculture cluster village tracts. These included 151 growout farms producing food fish for sale and 73 specialized nurseries producing juvenile fish “fingerlings” for sale to growout farms. In addition, 113 crop farming households and 347 non-farm (landless) households were surveyed within the cluster.⁵

A three-part survey instrument was used, comprised of:

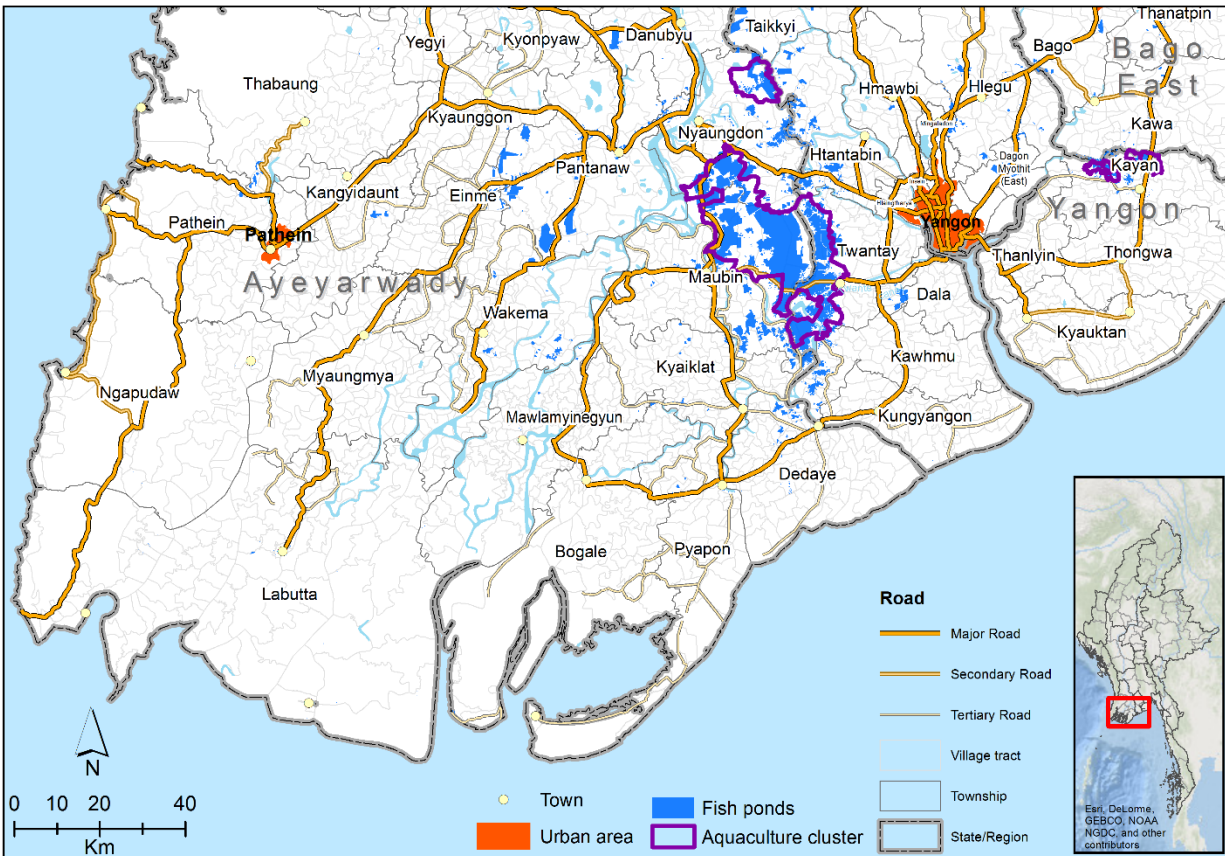
- 1) A *household* section, containing modules on household composition, off-farm employment, land and asset ownership, and consumption. This was administered to all households.
- 2) An *aquaculture* section, administered to all households operating growout farms or specialized nurseries. The instrument included modules on pond holdings and tenure; quantities and costs of inputs used (including labor), and the quantity and value of fish produced. Separate questionnaire modules were used to collect production data from growout farms and nurseries, in recognition of differences in the production logics of the two activities.
- 3) An *agriculture* section, divided into two sub-sections on monsoon season and dry season field crop cultivation, and incorporating modules capturing data on landholdings input application and costs (including labor); and crop yields, sales values and marketing practices.

³ MAAS collected data from areas where paddy cultivation was the main farming activity (agriculture cluster village tracts). This article presents data from aquaculture cluster village tracts only.

⁴ Specifically, the three regions Ayeyarwady, Yangon and Bago contain 90% of all aquaculture pond in the country, and the selected village tracts are home to 47% of the ponds in these three regions.

⁵ The full MAAS survey also includes an “agriculture cluster”, featuring an additional 15 village tracts, 29 enumeration areas, and 417 households. In total, the full dataset has 1,102 households, representative of 37,390 households. Only the aquaculture cluster economy was modeled for this article.

Figure 1. Location of Ponds and Surveyed Aquaculture Tracts



3.2 Sample characteristics

This subsection presents some basic descriptive statistics from MAAS on the agrarian structure of the aquaculture cluster and selected aspects of fish farming, crop production and labor therein. This information provides context for the interpretation of modelling results presented later in the text. More information can be found in (Ben Belton, Filipski, & Hu, 2017).

Levels of landlessness in aquaculture cluster village tracts are high, at 70%. Twenty percent of households are primarily engaged in crop farming and 10% practice aquaculture. The large share of the population dependent entirely upon non-farm employment means that the size of spillovers generated by agriculture and aquaculture play a particularly important role in determining the welfare of households in the cluster.

Two types of fish farm were surveyed: (1) specialized nurseries, (growing juvenile fish “fingerlings” for sale to growout farms). These comprised 41% of fish-farms; (2) “growout” farms producing food fish for the market (59% of fish-farms). Among growout farms, 51% were under 10 acres or less in size. For the purposes of this paper we define these small fish farms. The 49% of growout farms of more than 10 acres were defined as large.

Households operating fish growout farms own more than three times more land than crop farming households. The average crop farming household owns 9.8 acres of land (median 6.1). Households

operating growout ponds own an average of 29 acres of land (median 10 acres). Specialized fish nurseries are much smaller (mean 3.7 acres, median 1.7 acres). The all-household average area of land owned (including households without agricultural land) is 4.2 acres, with a median of just 0.16 reflecting very high levels of landlessness.

Fish production and crop farming are both highly commercially oriented. More than three quarters of the paddy crop, and almost all of the pulses (mainly green gram and black gram) produced in the study area were sold. Although 93% of growout farms reported consuming some of the fish they harvested, either directly or as gratuities to workers, the quantities consumed represented less than 1% of total production among large and small farms alike. Farms referred to here as 'small' are therefore similar to the small and medium commercial farms that feature in the "SME narrative" (outlined above), rather than the 'traditional' semi-subsistence farms that populate the "small-scale" narrative.

Fish growout farms specialize primarily in the production of carp species, the most important of which are rohu, catla and mrigal (stocked by 94%, 74% and 60% of farms respectively). Nursery farms specialize mainly in nursing these same species. Many large farms vertically integrate nursing functions, but the market for seed is vibrant: two thirds of all growout farms obtain at least some of their fingerlings from off-farm. This share rises to 85% for small growout farms. Almost all fish seed produced by specialized nurseries is sold to growout farms located in the aquaculture cluster. Fish seed nursing is thus a locally important backward production linkage.

Much land in the aquaculture cluster is low lying and vulnerable to heavy flooding during the monsoon. As a result, just over half of farms there are limited to production of a single irrigated dry season rice crop. Forty four percent of farms produce a monsoon paddy crop, followed by a dry season crop of pulses (mainly black gram, with some green gram).

Average returns from aquaculture are more than four times higher than those from agriculture. The average gross margin earned by fish growout farms is \$646/acre. Nurseries generate similar returns (\$681). There is relatively high disparity in the incomes from fish-farming (the median for growout farms is \$333/acre, about half of the mean). However, this still lies well above the average gross margins for monsoon paddy, dry season paddy and black gram (\$85/acre, \$128/acre and \$174/acre, respectively). The all crop average gross margin is \$153/acre.

Differences in profitability and scale among farm enterprises are reflected in differences in consumption expenditures (a proxy for income). Members of households that operate growout farms have an average annual consumption expenditure of \$1525 per capita. For members of nursery farming households, the figure is \$971. The average for households not engaged in aquaculture (crop farming plus non-farm) is \$689. This gap suggests that fish farming households may generate larger consumption linkages than non-aquaculture households, provided that they spend part of this income on locally produced 'non-tradables'.

Fish farms generate demand for almost four times more person days of labor (unpaid family labor, plus hired casual labor and hired long-term labor) per acre/year than crop farms (24 days versus 94 days, on average). Low demand for labor in agriculture relative to aquaculture reflects the highly seasonal nature of the former. For example, jobs like weeding field crops are performed only occasionally, whereas tasks such as feeding and guarding fish must be performed daily throughout the production cycle, which averages close to one year in duration. Agriculture's low demand for labor also reflects high levels of

agricultural mechanization, and the widespread use of other labor saving practices such as broadcasting paddy seed.

Among fish growout farms, those under ten acres generate by far the greatest relative demand for labor (152 days/acre/year). Large fish farms generate an average demand for labor of 32 days per acre/year. Differences in labor demand from large and small farms likely reflect economies of scale for certain types of labor (e.g. the number of person hours required to guard a 20-acre pond may differ little from the number required to guard a 5-acre pond). Conversely, large, well-resourced farms are more likely to invest in capital intensive labor saving technology, both for pond construction and maintenance (mechanical backhoes) and pond operation (e.g. water pumps, boats). As shown later, the differences in employment multiplier effects among crop agriculture and small scale and large scale fish farming have very significant implications for the magnitude and distribution of spillovers generated.

3.3 LEWIE modeling

Background. Local Economy-wide Impact Evaluation (LEWIE) modeling was developed to reflect the fact that local economies, like national or regional economies, function by way of interconnected markets (Taylor, 2013; Taylor & Filipowski, 2014). At the local scale, the prices of certain goods, services, and factors can be influenced by local supply and demand conditions. Typically, the price of items that are not easily traded outside of the local economy (such as land, local services or, to a lesser extent, labor) will be more responsive to local market conditions than items for which markets are seamlessly integrated at the national or international level (Abdulai, 2006; Fackler & Goodwin, 2001). In our case, rice and locally-produced fish are both almost entirely sold through Yangon, such that local demand in the cluster has virtually no bearing on sales prices.

The other insight central to LEWIE modeling is the fact that rural households participate to local markets both as producers and consumers of goods and services, and as providers and users of factors. For example, while rural households may benefit from higher prices of grain as producers, they will lose as consumers. Similarly, households will gain from higher wages if they work outside their own household, but they also need to increase pay for workers hired on their own farms.

In view of these considerations, the core elements of LEWIE are agricultural household models (Singh, Squire, & Strauss, 1986), which capture the dual nature of farm households with their production and consumption behavior. LEWIE nests several of these models into an economy-wide model, reflecting the way households trade amongst themselves in the local economy, as well as with the outside economy (Taylor & Filipowski, 2014).

LEWIE models have been used to evaluate local economy-wide impacts of anything from cash transfers (Filipowski, Taylor, Thome, & Davis, 2015; Thome et al., 2013), irrigation investments (Filipowski, Manning, Taylor, Diao, & Pradesha, 2013), refugee settlements (Taylor et al., 2016), or price volatility (Filipowski, Aboudrare, Lybbert, & Taylor, 2017). Using LEWIE to study the impacts of aquaculture development represents not only a novel application of the methodology, it also requires adapting the model to accommodate simulations based on land expansion or conversion between different uses.

In practice. Mathematically, LEWIE models are structural general-equilibrium (GE) models, rooted in the Computable General Equilibrium (CGE) tradition (Löfgren, Robinson, & Harris, 2002). They are systems of equations that represent both the production side and the consumption side of all markets in the

economy (appropriately aggregated), and the prices and trade volumes that make those markets clear. The full model statement is available in appendix A. In general terms, the system of equations is organized as follows.

All households in the economy are categorized into one of several groups (in our case, six). Similarly, all goods (and services) in the economy are categorized into one of several goods (in our case, seven). In the model, goods can be produced locally (by the households) or purchased from the outside (“imports” into the local economy). Household who produce the goods do so by combining factors of production such as land, labor (family or hired), purchased inputs such as fertilizer or feed, and intermediate inputs coming from other production activities. Factors are combined following a Cobb-Douglas production function (fixed factor shares), but intermediate inputs follow a Leontief schedule (fixed relative quantities) (Leontief, 1986). Thus, the relative amounts of factors used in production are determined by their relative prices.

The households that own factors used in production are compensated in the form of income, which they can use to purchase goods. These purchases are represented by a Stone-Geary consumption function, meaning that households satisfy their minimum consumption requirements and spend the rest of their income per fixed value shares. Household savings and investments are treated the same way as goods, and represent a fixed share of income. Since we run the model over a one-year period, amounts saved or invested do not impact production.⁶

Prices in the economy are determined either by the interaction of local supply and demand (for “non-tradable” goods, meaning not traded outside of the economy), or determined exogenously (for “tradable” goods). Whether they are tradable or not, all goods must satisfy market-clearing equations, which complete the model. These equations guarantee that, for each good or factor, the total sum of amounts supplied (produced, imported or initially endowed) are accounted for somewhere on the demand side (for consumption, export, or use in production). Because the model is based on households, the same equations exist at the household level: the sum of all endowments, purchases, or production in the household must match total consumption, sales, or use in production.

The choice of how to distinguish household groups, goods and factors in a LEWIE model is guided by the specific research questions one hopes to answer through simulations. Given our focus on aquaculture and farm size, in this application we distinguish five groups: three fish-farming groups (small-scale, large-scale, and nurseries), crop farmers, and non-farm households. Each household in the dataset is mapped to one of these five groups. The same is true for activities, goods, and factors in the model. All accounts in the model can be seen

⁶ When running the model over multiple periods, savings and investments can be used to update production parameters and simulate dynamic growth – but we do not apply these techniques in this paper.

Table 1.

Table 1: Accounts in the LEWIE model

Code		
Households	Description	Number of observations (weighted percent of households)
F _{Sm}	Small fish farmers (<10 acres)	64 (3%)
F _{Lg}	Large fish farmers (>=10 acres)	95 (3%)
Nurs	Fish nurseries (without growout ponds)	66 (3%)
Ag	Crop farmers (without ponds)	113 (20%)
LL	Landless households (all non-farm)	347 (71%)
Activities	Description	Households Participating
Crop	Crop production	All landed households (F _{Sm} , F _{Lg} , Nurs, Ag)
Fish	Fish farming	Small and large growout farms (F _{Sm} , F _{Lg})
F _{seed}	Fish nursery farming	Growout farms and pure nurseries (F _{Sm} , F _{Lg} , Nurs)
Prod	Other local production (ex: crafts)	All households
Ret	Retail	All households
Ser	Services	All households
Commodities	Description	Market Assumption
Crop	Locally produced crops (mostly grain)	Tradable (exogenous price)
Fish	Locally produced fish	Tradable (exogenous price)
F _{seed}	Fish seed	Non-tradable (local price)
Meat	Meat	Tradable (exogenous price)
Prod	Other locally produced goods	Tradable (exogenous price)
Ret	Locally purchased retail goods	Non-tradable (local price)
Ser	Locally provided services	Non-tradable (local price)
Out	Goods and services purchased outside of the cluster	Tradable (exogenous price)
Factors	Description	Market assumption
Land	Land	Fixed in production
Labor	Labor	Non-tradable but highly elastic supply
Capital	Capital	Fixed in production
Input	Commercial input (fertilizer, fish feed, etc.)	Tradable (exogenous price)

One of the strengths of these types of model is that they accommodate a wide variety of “market closure assumptions”, or rules by which the modeler chooses to depict how a good or factor is traded. In this case, as can be seen in

Table 1, we consider land and capital to be fixed in production, for each activity and each household (this is a common short-term assumption). Labor is only traded within the village (another common short-term assumption), but its supply is highly elastic (meaning that we assume that there exists unemployed or underemployed labor in the economy).⁷ Purchased inputs are tradable goods, purchased at a fixed price from outside traders. Crops and fish are sold at fixed prices, determined outside of the economy. Retail goods are purchased at a fixed price from outside traders, but the markup imposed by local retailers is endogenous and responds to local demand.

3.4 Model calibration

Calibration process. Calibrating LEWIE models requires estimating all production, consumption, and trade flows in the local economy. Those data are usually calibrated from household surveys, such as Living Standards Measurement Surveys (LSMS). Average values of production and consumption are computed for each type of household. To accurately represent the full economy, these averages are then multiplied by a weighted number of observations, appropriately accounting for sampling bias. Econometric estimates of production and consumption functions provide the factor value shares and expenditure shares. This allows us to compute all the amounts consumed or produced by each household type.

In addition to production and consumption estimates, this economywide picture needs to define flows of goods into and out of the economy. For each item mentioned in the production, consumption, or business sections of the questionnaire, respondents were asked where it was purchased or sold.⁸ We rely on these provenance and destination questions to determine what fraction of production inputs are coming from the local economy (within the village tract or a neighboring village tract) and what fraction are coming from external sources (urban areas or rural areas of other townships). Finally, we use the net balances of local supply and demand to determine trade with the “rest of the world”, including trade in commodities and exogenous household incomes. This completes calibration and yields the picture of a balanced economy: one where incomes and outlays are equal for each account.

Monte-Carlo validation procedure. Simulation methods do not offer the possibility to assess the statistical significance of results. However, because we calibrate the model from econometrically estimated parameters, we can exploit these estimations to provide an additional measure of confidence for our results, using a “Monte-Carlo” approach (Robert, 2004). For each estimated parameter, we can replace the point estimate with a random draw from the parameter’s distribution, which we assume is normal (truncated at zero if necessary). We do this repeatedly N times, simultaneously drawing all parameters at random from their distribution, and calibrating the model N times, once with each set of

⁷ This assumption does not drive results. Some indications that the rural labor market in Myanmar is tightening exist, but unfortunately no elasticity estimates are available. The results presented in the paper were performed with labor supply elasticity equal to 100 (highly elastic), but repeating simulations with labor supply elasticity set to 1 (moderately elastic) or to 0.1 (inelastic) does not alter results in any substantive way, and leads to the same conclusions. In addition, since the elasticity assumption is common to all simulations, it has no bearing on the relative comparisons.

⁸ Such questions are not standard for LSMS-type surveys, and constitute one of the prerequisites for running a LEWIE analysis. For purchased inputs and consumer goods respondents were asked “From where did you get [item]? a) This village, b) This village tract, c) Neighboring village tract, d) Nearest town, e) Yangon City, f) Other township (specify), g) Other region (specify)”. The corresponding questions are asked about items sold in the production and business sections. Specifically, we considered answers a) b) and c) to be local-economy transactions, and all other answers to be “rest-of-world” transactions.

parameters. We then run the simulations N times, obtaining a different result every time. The variability in those results reflects the precision of our parameter estimations: imprecisely estimated parameters will produce more variability in the results. At the end of the procedure, we report not the result of one run of the model, but rather the mean value of all N results. This also allows us to report the standard deviation around that mean value, thus conveying a measure of confidence. For this work, we set N=200, which was enough to obtain stable results.⁹ This procedure expands and streamlines sensitivity analysis, and is another salient feature of this analysis.

Production and consumption parameters. We present the value shares of factors and intermediate inputs used in fish and crop production in

⁹ Using too few repetitions leaves the model vulnerable to outliers, but we found that a few dozen repetitions were sufficient to obtain stable results.

Table 2 (other activities in appendix). Factors are production inputs that produce value added: land, labor, capital, and commercial inputs into production (feed, fertilizer). Intermediate inputs are seeds and operating costs (taxes, financing, transportation costs, etc.). Intermediate inputs are treated differently in the production function because they must be added in fixed proportion and cannot be substituted for one-another.¹⁰ Value-added shares were computed by regressing the total value of output (logged) on total value or quantity of land, labor, capital, and commercial inputs (also logged).¹¹ Intermediate input shares were computed directly as the value of those expenses over total output value.¹²

Comparing production functions between different households yields several insights. First, and most importantly, small fish farms tend use less feed inputs and capital than large farmers. Instead, their production function is relatively more labor- and land-intensive. This insight is key for the remainder of the analysis, as it explains why smallholders may generate more economic activity locally than their larger counterparts. The bottom part of the table suggests that fish farming requires more intermediate inputs than crop farming. As a fresh product, fish require much higher operating costs at harvest time (ice, transport). Aquaculture farms also tend to operate using informal loans and have much higher financial costs than agriculture, which is financed primarily by government subsidized crop loans. Seed accounts for a similar share of costs for fish growout farms and crop farms, but a much higher share for fish nurseries. These purchase large quantities of hatchlings, but require low feed inputs relative to growout farms.

¹⁰ For instance, a small field that was plowed can yield the same output as a large unplowed field (labor substitutes for land area). However, neither field yields anything without seeds, no matter how large or how much it gets plowed (land and labor cannot substitute for seeds).

¹¹ The log-log regression is consistent with a Cobb-Douglas production function.

¹² Fixed proportion intermediate inputs are consistent with a Leontieff production function.

Table 2: Production function parameters for agriculture and aquaculture

Value shares of total output		Small fish farms (Up to 10 acres)	Large fish farms (>10 acres)	Fish Nurseries	Crop farms
Factor shares	Land (or pond)	25%	23%	11%	18%
	Labor	13%	7%	5%	9%
	Capital	2%	6%	14%	23%
	Production inputs (incl. feed, fertilizer)	39%	50%	24%	40%
Intermediate input shares	Seed (fish or crop)	9%	8%	30%	9%
	Other expenses and operating costs	12%	7%	15%	1%
Total		100%	100%	100%	100%

Source: Author estimations.

Notes: Factors create value added (top 4 lines) and get combined in a Cobb-Douglas function (fixed value shares), while intermediate inputs requirements follow a Leontief function (fixed proportions). Production parameters for remaining activities (retail, services, etc.) are provided in the appendix.

Table 3 shows expenditure shares for all household types in the model. These were also obtained from log-log regressions of total expenditure on consumption spending in each category. Overall, the households display relatively similar expenditure patterns. It is notable, however, that large fish farmers (which are on average wealthier) spend a far greater share of their income (43%) outside of the economy than other types of household. In local economy-wide terms, such expenditures are equivalent to “leakages” out of the local economy, and do not generate spillovers.

Table 3: Consumption shares of income for households in the model

Goods or services	Small fish farms	Large fish farms	Nursery farms	Crop farms	Non-Farm
Crops	16%	6%	11%	18%	19%
Meat	11%	5%	9%	10%	11%
Fish	5%	3%	4%	5%	6%
Other local production	3%	5%	3%	2%	7%
Local retail	22%	27%	29%	39%	28%
Local services	14%	12%	14%	9%	8%
Outside purchases	30%	43%	30%	16%	21%

Once calibrated, the model is at equilibrium, meaning that the values we chose for variables and parameters constitute a solution to the system of equations that is the model. Simulations are then performed by changing specific parameters of the model and running an algorithm to find the new variable values that constitute a solution. In what follows, all our simulations will be based on exogenously changing the value of land assets of given households. The new model solution then tells us how market balances in the economy are likely to adapt in response to such an event.

3.5 Simulation design

We use the model to simulate five scenarios, with the goal of informing two comparisons: first, to compare fish farming to crop farming; second, to draw out differences between smallholder and large-holder aquaculture. The five scenarios are outlined in **Table 4**.

Simulation 1 is a hypothetical scenario by which a previously unused acre of pond is allocated to a small fish farmer. This is akin, for instance, to land distribution or reallocation, from unused public land to private pond. The pond is assumed to be previously unused, so that it is not taken away from another household, nor does it reduce the total area of arable land in the economy. Similarly, the scenario in simulation 1 does not require any cost to the farmer. Though such a scenario is not very likely to occur in real life, this simplification is intentional. If we were to model the pond being purchased or excavated, the related payments to previous owners or workers would obscure the simulation results and make it harder to trace the impacts through the model. Simple simulations allow us to isolate the interlinked impacts of increasing pond area, and facilitate comparison between scenarios.¹³ In modeling terms, simulation 1 is carried out by exogenously increasing the value of pond assets held by the small fish farmer group (SFF) by \$166 (MMK 200,000), the average per-acre rental rate for fish ponds reported in the MAAS survey.¹⁴ All the farmers in each group are represented in aggregation by one representative households. This simulation can thus be interpreted as an average small farmer receiving a free acre of pond.

Simulation 2 is exactly the same as simulation 1, but the recipient of the free pond is the second household group, large fish farmers (LFF). Again, the simulation entails exogenously increasing the value of their pond assets by the rental rate of \$166. Simulation 3 is quite similar again, but this time it is the crop farmer group (CF) that receives a free acre of land. In that case, the value of the acre is \$58 (MMK 70,000), reflecting the lower rental-rate on crop land as opposed to ponds.

The model fixes land inputs in the simulations, such that the household receiving the acre of land (or pond) will not leave it fallow nor resell it to another household, but rather will put that land into production. This means that in simulation 1, the small fish farmer household will adapt the quantity of inputs it uses (fish seed, labor, etc) to reflect its increased pond area. This will affect the quantity of fish it produces and the income it generates from fish farming. It will also affect the local demand for inputs, and thus indirectly impact any other household that either provides or purchases those inputs. These updated incentives lead the other households to adapt their behavior, which in turn also affects local market demand, prices, and all households participating in these markets. The model helps trace these rippling effects through the local economy.

Simulations 3 and 4 are similar to simulations 1, 2, and 3, but involve a trade-off. In simulations 3 and 4, we convert one acre of land from crop farming to fish farming. In practice, this means that we increase pond assets by the value of a 1 acre pond, and at the same time reduce cropland assets by the value of a 1 acre piece of crop land. We do this for the small fish farmer in simulation 3, and for the large fish farmer

¹³ In addition, an important cost of putting a previously unused acre of land into production might exist if that land had value for local inhabitants as a common property resource, for instance as a source of firewood or wild fish. However, since the cost of losing access to that resource would be identical in all three simulations it makes sense to assume it away when comparing these scenarios. Assessing those costs is not the goal of the current research, but assuming them away in these simulations is by no means intended to minimize their importance.

¹⁴ Conversion rate used throughout the paper: MMK 1200 = USD \$1

in simulation 4.¹⁵ Again, we limit the complexity of the simulation by assuming that the converted land does not change hands, and that the digging of the pond is costless.¹⁶ Comparing simulations 1 through 5 allows us to highlight how differences in the production parameters between small fish farms, large fish farm, and crop farms, translate into differentiated local economy-wide impacts.

Table 4: Simulation scenarios and parameters

	Scenarios: One previously unused acre of land is put into production			Scenarios: One acre switches from agricultural use to aquaculture use	
Simulation:	Sim 1	Sim 2	Sim 3	Sim 4	Sim 5
Rationale:	Give 1 acre to small fish farmer (value USD 166)	Give 1 acre to big fish farmer (value USD 166)	Give 1 acre to crop farmer (value USD 58)	Allow small fish farmers to convert one additional acre	Allow large farmers to convert one additional acre
Target household	Small fish farmer	Large fish farmer	Crop farmer	Small fish farmer	Large fish farmer
Change in value of pond assets	USD 166	USD 166	-	USD 166	USD 166
Change in value of cropland assets	-	-	USD 58	USD -58	USD -58

3.6 Measuring inequality

The LEWIE portrays all households in the cluster grouped into land- and pond-ownership categories. This makes it possible to measure income disparities between them, and how those disparities change in the simulations. We measure inequality with the Theil index, which is a special case of the general entropy index and a commonly used statistic for measuring income disparities.¹⁷ The formula for the income inequality index (τ) is as follows:

¹⁵ We do not model giving a pond to the crop farmer household because we do not have fish-farming production parameters for them (crop-farming household do not participate in any fish farming activity, by definition). We could assume that these farmers would act the same way a small fish farmers act, which would be largely redundant to simulation 4.

¹⁶ Excavating a pond costs the same price no matter which household does it, so it can be assumed away in the comparison.

¹⁷ Since the model groups all households into five types, it does not lend itself to the drawing of income distributions or Lorenz curves. For this reason, we opted to measure inequality with the Thiel index rather than the Gini coefficient.

$$\tau = \frac{1}{N} \sum_{i=1}^N \frac{x_i}{\mu} \ln \left(\frac{x_i}{\mu} \right)$$

Where x_i is the income of household i , N is the total number of households in the economy, and μ is the mean income of all households. If the sample was perfectly egalitarian, all households in the dataset would have income equal to μ and the Theil index would be equal to zero. The larger the index, the greater the income inequality in the sample.

4 Results and discussion

4.1 Impacts on production

We first examine the direct production effects of giving or converting land in our simulations, charted in Figure 2. Each bar represents the total increase in value of locally produced output for a given commodity in each simulation. Each simulation was in fact repeated 200 times, each repetition involving a slightly different random draw of model parameter (Monte-Carlo procedure), such that the top of the bar is in fact the mean of the 200 results obtained, while the error brackets around the top of each bar report the standard deviation (SD) of those 200 results. Thus, in all our repetitions of simulation 1, the production of local fish increased on average by \$585, with \$126 standard deviation. Reporting results in such fashion helps us convey the robustness of our results to the variation and uncertainty in the data used for calibration.¹⁸

Simulation 1 shows that handing a small fish-farming household an additional acre of land generates a value of \$585 (SD=\$126) in fish production (without altering crop production). Fish production increases by \$548 (SD=\$121) in simulation 2, when the large fish farmer is receiving the additional acre. The output in simulation 1 is slightly higher than in simulation 2, reflecting the fact that small households farm their ponds somewhat more intensively. However, the difference in overall productivity between small and large fish farmers is limited. As we will see below, however, the differences in production technologies and expenditure patterns between small and large fish farmers lead to greater differences in terms of local economy-wide impacts.

Increasing cropland by one acre (Sim. 3) only increases crop output by \$148 (SD=\$24), suggesting that aquaculture generates more than four times more value per acre than agriculture, consistent with field observations. In simulations 4 and 5, the fish farmer converting an acre of land from cropland to pond needs to forego some crop production in order to increase fish production (\$165).

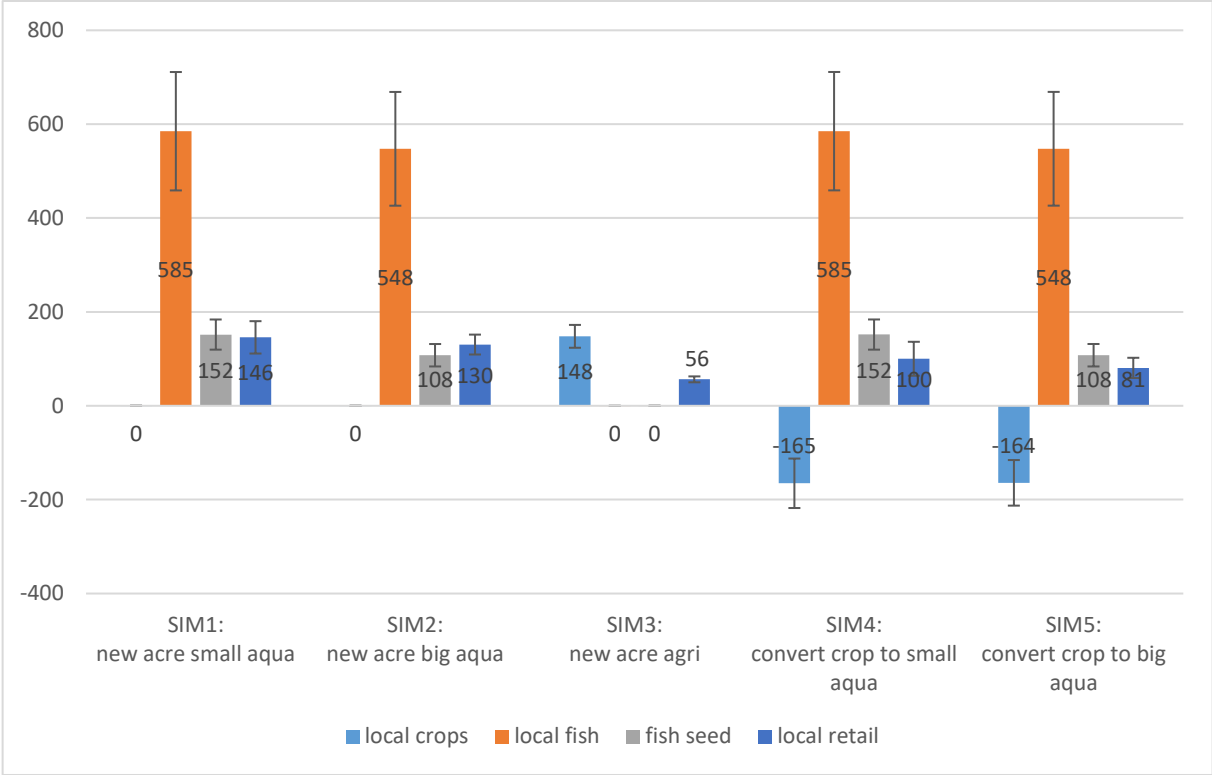
In addition to shifts in fish and crop production, simulations 1 and 2 raise the production of fish seed, a necessary input into the production of fish, by \$152 and \$108 respectively. All simulations also lead to an increase in retail output, which is comprised of both the local sale of farm inputs and consumer goods. The retail spillover is far from negligible: ranging from \$56 (SD=7) to \$146 (SD=37). In simulations 1 and 4 it rivals the size of the direct production impact of an acre of cropland in Sim 3.

Finally, the model led to small impacts on other activities, not shown in the figure in the interest of clarity. All simulations increase slightly the supply of service activities (the maximum was \$37 in simulation 1), in

¹⁸ While these brackets are obtained by exploiting the statistical distributions of our estimated model parameters, they themselves come from bootstrapped simulation (not statistical inference), and should not be thought to convey statistical significance.

response to rising incomes. All simulations also lead to very small decreases in the value of other local production such as artisan crafts, but in almost negligible amounts (the largest decrease was of \$11 in simulation 1). These slight decreases are due to the reallocation of productive resources away from those activities and in favor of aquaculture. Running our simulations with inelastic labor supply forces households to reduce other local production in favor of fish and retail, but does not substantially alter the other results presented.

Figure 2: Change in total value of local production (USD)



4.2 Full impact on incomes

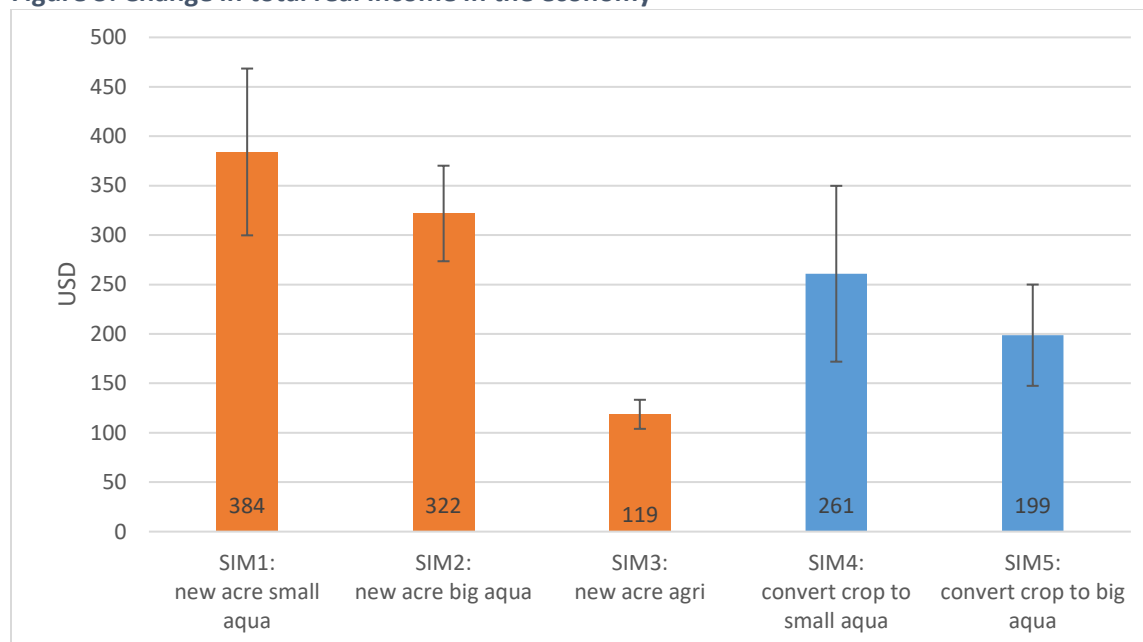
We report the overall impact of each of the five simulations on incomes in the economy in Figure 3. Each bar should be interpreted as the change in annual income triggered by the simulated shock, summed across all households. Bars are lower than those in Figure 2, which reported gross production value and failed to net out any production cost. In contrast, Figure 3 reports the net effects on household income in real terms, summing across all income sources for all households, and accounting for changes in consumption prices (a local CPI is computed in the simulations).

Comparing simulations 1 and 2 to simulation 3, we see that an acre of pond generates far more income in the economy than an acre of crop land (\$322-\$384 against \$119). This is expected, since the rental rate for ponds is higher than the rental rate for cropland, likely reflecting their relative value for a potential user. However, this comparison confirms that this remains true for the whole economy, as well as the individual farmer privately operating land. We examine those spillovers in more detail below.

As expected, the bars in simulations 4 and 5 are smaller than in 1 and 2, because farmers are converting their existing land, thus they give up an acre's worth of cropland to gain a new acre of pond. The positive bars in simulations 4 and 5 confirm that aquaculture generates higher revenues per acre than crops.

Comparing simulation 1 to simulation 2, we also see that giving an additional acre of pond area to a small fish farmer generates about 20% more income (\$384, SD=\$84) than handing the same pond to a large fish farmer (\$322, SD=\$48). The same is true with simulations 4 and 5: the total income generated by the conversion in the former (\$261, SD=\$89) is about 30% higher than in the latter (\$199, SD=\$51).

Figure 3: Change in total real income in the economy



Source: simulation results

4.3 Disaggregating spillovers

In this subsection we disaggregate income to report the change in income for each household type in the model. The bars in Figure 3 are aggregated: they sum up the direct income from the farming activities, and all the spillover incomes generated through backward and forward linkages, for all households. In **Figure 4**, each group of bars represents the five types of households in the economy for each given simulation. In each group, the full-color bar represents the household affected directly, while other households are represented by striped bars.

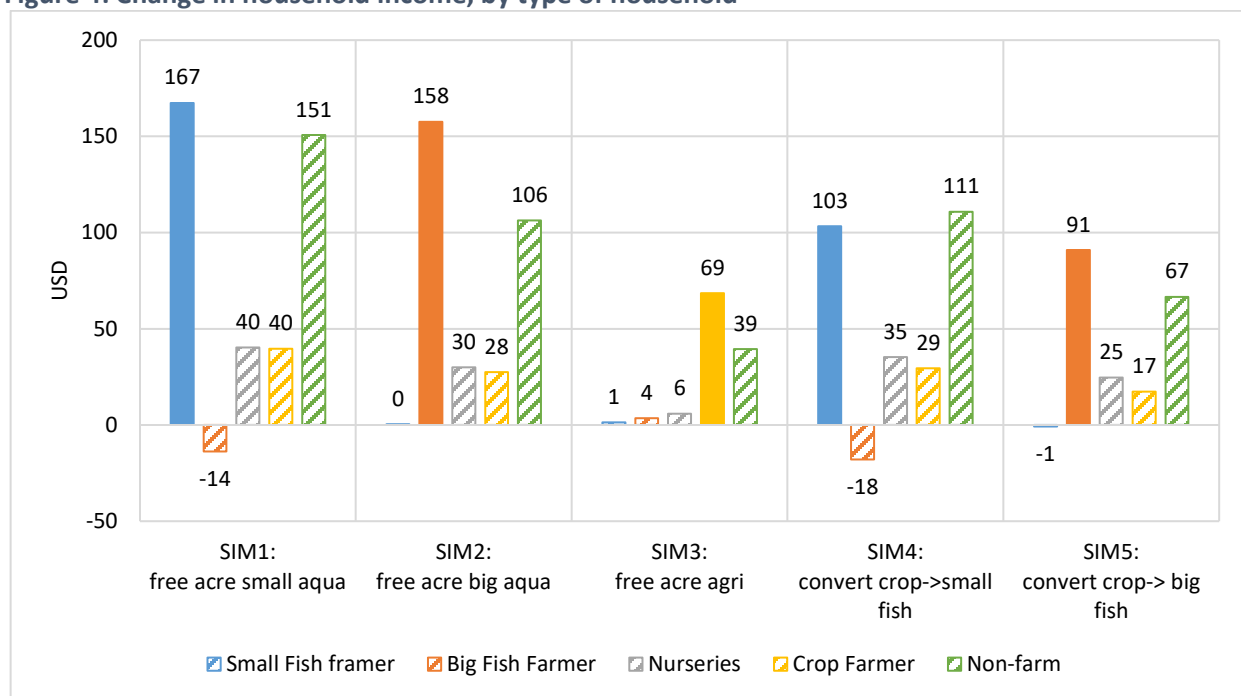
In simulation 1, the tallest bar (\$167) represents income increases for the small fish farmer (the recipient of the pond). Nursery farms also gain a modest income (\$40) providing the seed for the new pond, mirroring the increase in fish seed production seen in Figure 2. Large fish farmers are the only household type to lose income in simulation 1 (-\$14). This is because the additional demand for fish seed and labor bids up the prices of these items (which are in limited, albeit elastic supply). This raises costs for all fish farmers, including large farms. This observation serves as an important reminder that, as with any intervention, market dynamics are likely to create losers alongside the winners.

A striking result in simulation 1 is that the bar representing non-farm households (\$151) is nearly as tall as the bar for small fish farmers. Non-farm households are landless households who provide a large share of the labor working on fish farms. Non-farm households also participate in commerce (from petty trade to formal retail): they benefit from the extra spending needed for production on the additional pond, and from the multiple rounds of consumption spending triggered by increased incomes in the economy. Retailers benefit from purchases made by the small fish farmers, by the laborers who worked the new pond, the nursery farm who provided the seed, the retailers who sold goods to them, etc. This highlights the importance of forward and backward linkages, particularly in input, labor and retail markets. Non-farm households are among the two top gainers in all simulations, and in simulation 4, they even gain more than the household receiving the land. Crop farmers gain modest amounts of income through the same channels, as they also participate in the labor and retail markets.

Simulation 2 presents a very similar pattern to simulation 1, but with all bars somewhat smaller. The top gainers are the large farmers, who own the additional pond and see revenues increase by an amount just slightly lower than the revenue of small fish farms in simulation 1. The next largest gainers are non-farm households, but their income increases less than they did in simulation 1 by about a third (\$106 against \$151). Nurseries and crop farmers also gain less, while small fish farmers remain unaffected. An acre of pond operated by a large farm generates similar direct incomes as one operated by a small farm, but substantially lower indirect incomes.

Results from simulation 3 show that only two household types gain significantly from the transfer of an acre of cropland: the crop farming household itself (\$69), and the non-farm household (\$39). Fish farmers and nurseries gain only fractional amounts, which are the net balance of the gains and losses they may experience by their participation in labor and input markets. This suggests that that crop farming produces far fewer spillovers than fish farming, because it generates less demand for hired labor and does not rely on a local nursing industry.

Figure 4: Change in household income, by type of household



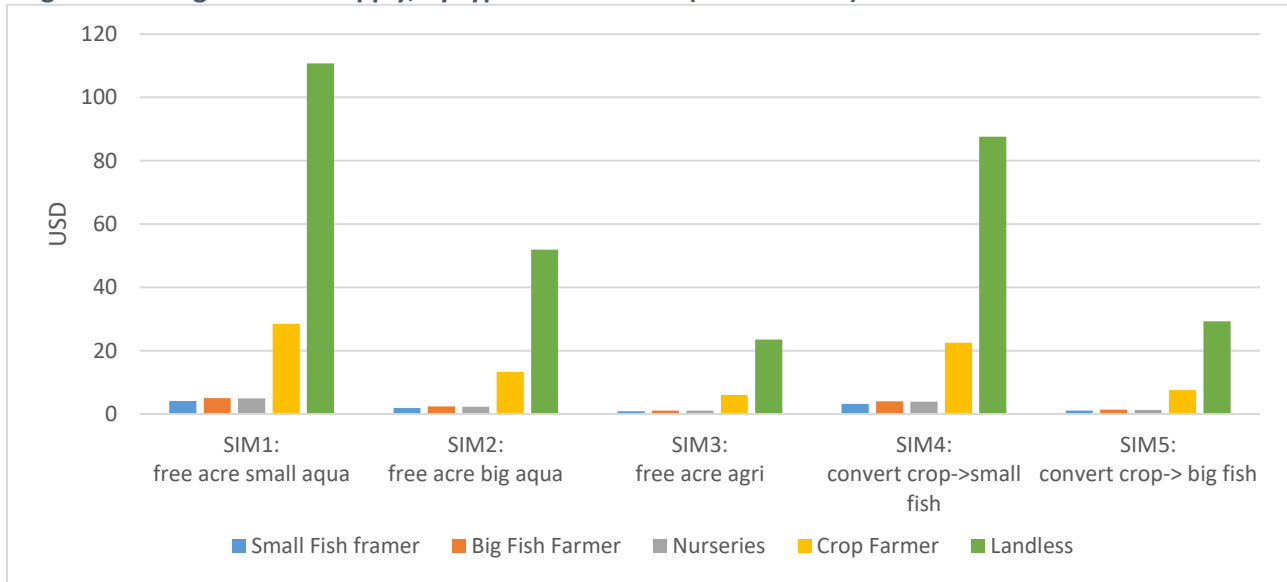
Source: simulation results. Full-colored bar represents target household in each simulation. Error brackets not reported in the interest of clarity.

In **Figure 5** we shed further light on the simulated incomes by looking at changes in labor supply coming from each household. In all simulations, non-farm households provide the bulk of the labor force. This explains partly why non-farm households are among the biggest winners in all simulations (as seen in **Figure 4**). Crop farmers also participate in labor markets, and provide the remainder of the labor force in all simulations. Fish farming households (small farms, large farms, and nurseries), who represent about 10% of the population, make only small contributions to the labor force. Simulations 1 to 3 all require an increase in labor supply in the economy to satisfy the demand needed to operate the additional acre. In simulations 4 and 5, an acre of land is converted into a pond, which releases crop-farming labor while increasing demand for fish-farming labor. Since fish farming is more labor intensive than crop farming, simulations 4 and 5 also lead to a net increase in labor.

Overall, small fish farms create much higher labor demand than large fish farms or crop farms, on a per-acre basis. Figure 5 also shows that simulations 1 and 4 entail a much larger increase in labor demand (and supply) than the others. As detailed above, the first reason for this is that, smaller fish farmers apply more labor per acre in their production process, while large farms benefit from economies of scale and capital-intensive technology. Handing small farmers an acre of land thus leads to a greater labor demand. This is amplified by the fact that smaller farms use more local inputs and generate slightly higher incomes from an acre. The associated demands for inputs or consumer goods also pull labor into production as a second-order effect.¹⁹

¹⁹ These simulations focus on pond operation alone. Taking pond construction into account would greatly increase labor needs in the first year, but not in any of the following years.

Figure 5: Change in labor supply, by type of household (value in USD)



Source: simulation results

4.4 Total spillovers

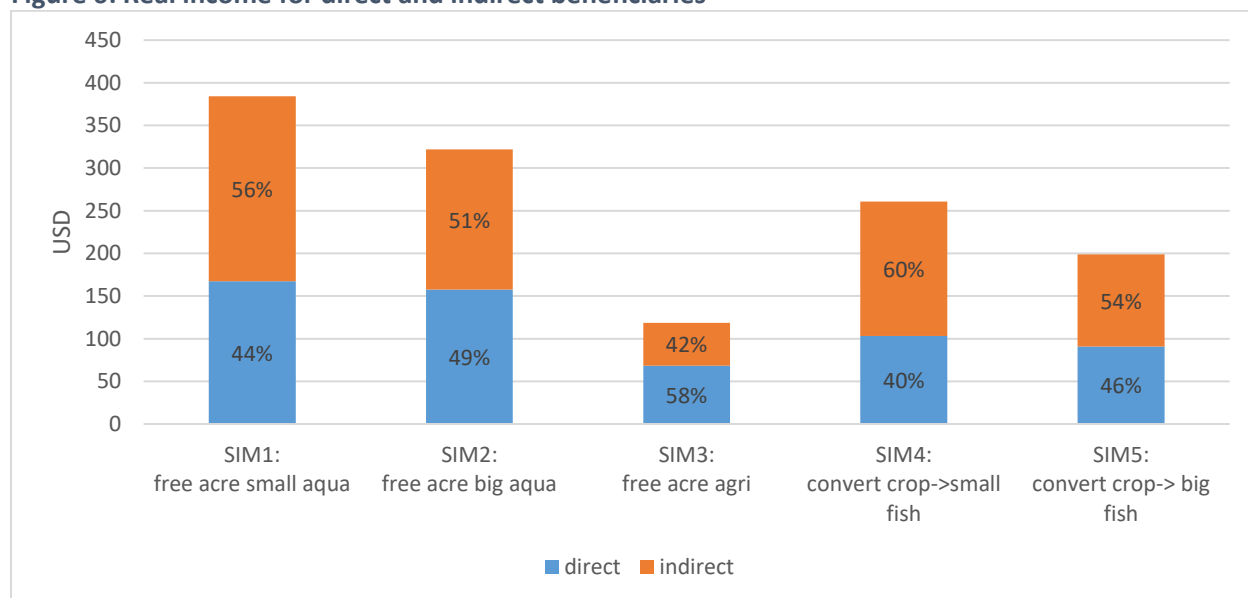
The spillover impacts can be summed up by contrasting, for each simulation, the income of the targeted household to the summed income of all other households. **Figure 6** shows the same bars as Figure 3, but split between direct beneficiaries (the household type receiving the acre, which varies depending on the simulation) and indirect beneficiaries (all other households).

All interventions create a non-negligible spillover, between 42% and 60% of the total income generated. In 4 out of our 5 simulations, the share of income accruing to indirect beneficiaries is above 50%, meaning that the indirect benefits generated through market spillovers are larger than the direct benefits accruing to the household who received the land. This highlights the economic interconnectedness of rural households and the importance of accounting for income spillovers when discussing rural economies.

Simulation 3 shows that 42% of the additional income generated by an extra acre of land accrues to households other than crop farmers. In simulations 1 and 2, the shares are 56% and 51%, respectively, suggesting that fish farming generates greater spillovers than crop farming. This reflects the fact that aquaculture is more demanding of inputs and labor than crop farming, so that operating an additional acre of pond is more likely to generate spillover incomes. In addition, purchases of fish seed, which is always locally produced, generate additional local spillovers through backward linkages to commercial nurseries.

The figure also suggests that small fish-farms generate more spillovers than large ones, both in absolute and relative terms. Small farmers given an acre of pond retain 42% of the total income generated, while large farmers retain 49%. When they convert a crop field to a pond, small farmers retain 40% of benefits, while large farmers retain 46%. This reflects the difference in production technologies: large farms use more capital-intensive technology, thus channeling more benefits to capital owners.

Figure 6: Real income for direct and indirect beneficiaries



Source: simulation results

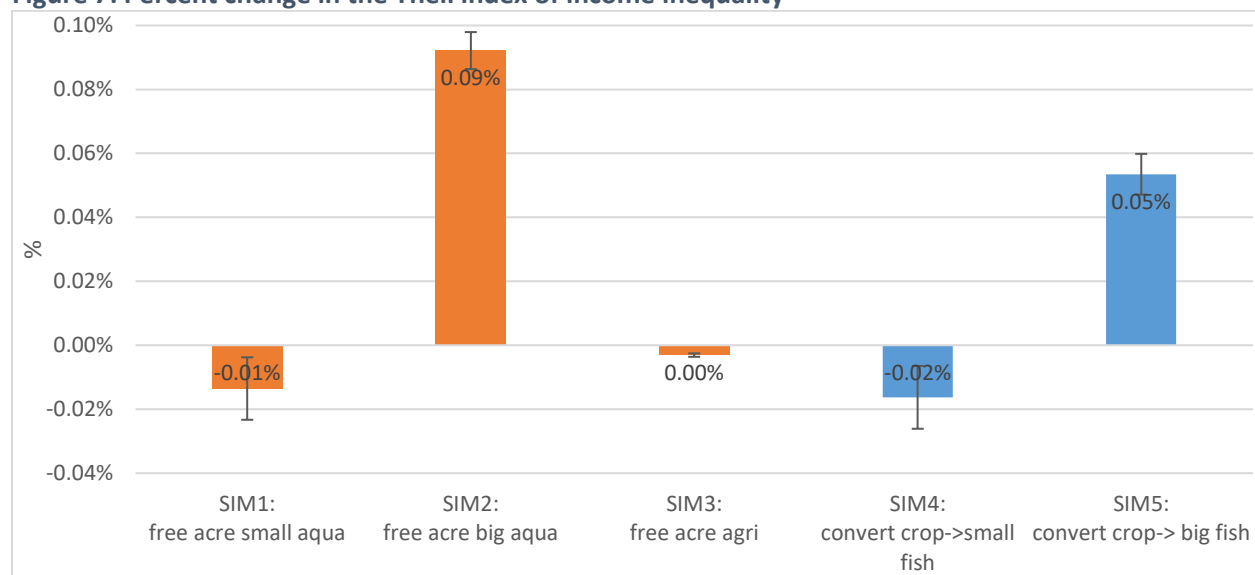
4.5 Impacts on Inequality

Lastly we turn to the impacts of aquaculture on inequality in the local economy. **Figure 7** shows the percent change in the Theil index for income associated with each simulation. An increase in the index represents an increase in inequality, and vice-versa.²⁰ Numbers are small because the value of the income created by a single pond represents small fraction of the value of the total income in the modelled economy.

Simulations 1 and 4 slightly reduce income inequality (-0.01% and -0.02% respectively), while simulations 2 and 5 increase it (0.09% and 0.05%). Meanwhile, an additional acre of crops has a negligible impact on inequality (sim 3). These results can be interpreted as follows. Large fish farm households are among the wealthiest in the aquaculture cluster. Increasing their incomes, either by increasing their landholdings (sim 2) or converting agricultural land to ponds (sim 5) amplifies this inequality. A small fish farmer receiving or converting land to ponds has an inequality reducing effect, because although they are somewhat better off than the population average, they generate large indirect income spillovers to landless laborers who sit at the lower end of the income distribution. For crop farmers, the small inequality increasing (direct) and inequality reducing (indirect) effects of raising landholdings cancel one another out.

²⁰ The magnitudes (-0.04%, 0.06% etc.) measure the percent increase in the entropic distance from the egalitarian state in the simulation.

Figure 7: Percent change in the Theil index of income inequality



Source: simulation results

5 Conclusions

This article presents the first structural model analysis of the relationship between fish farms and the local economy to which they belong. We constructed a LEWIE model of the economy of 25 fish farming village tracts in Myanmar, and used the model to: (1) simulate the economy-wide impacts of utilizing land for either aquaculture or crop production; (2) compare spillovers generated by small- and large-holder operated fish farms.

This analysis yielded the following results: First, as expected, fish farming in Myanmar generates much higher returns per acre to the farmer than agriculture. Second, importantly for the debate on aquaculture's contributions to economic development, fish farming creates income spillovers for surrounding households, the largest of which accrue to landless farm workers. Third, small commercial fish farms generate slightly larger direct incomes per acre of pond than large farms, and substantially larger spillover incomes. This is due to the propensity of the former to rely more heavily on labor and locally produced inputs, while the latter use more external inputs and capital. Fourth, increasing the area of ponds operated by fish farming smallholders has an income inequality-reducing effect, while the expansion of large fish farms raises inequality.

Our work makes three significant contributions. First, the methodological toolkit developed allows aquaculture to be viewed through an economy-wide lens that situates fish farms within the networks of forward and backward linkages that ultimately determine their performance as drivers of rural growth. Formalizing these linkages in a structural model rooted in general equilibrium theory allows the debate over the economic impacts of aquaculture to be addressed within a theoretical framework capable of generating robust empirical results.

Second, the findings contribute to ongoing debates over the role of aquaculture in poverty alleviation. Our results show that commercially-oriented fish farms can have positive impacts on the local economy

through income spillovers, and lend strong empirical support to the “SME narrative” on aquaculture’s role in rural development.

Third, simulation results have important policy implications, for Myanmar and beyond. The finding that aquaculture can generate much higher farm incomes *and* greater economic spillovers than crop farming is pertinent for Myanmar, where conversion of agricultural land to ponds is prohibited, and to many other countries that place restrictions on the expansion of aquaculture in the attempt to protect cropland (such as Vietnam, China, and India among others). The finding that large fish farms generate smaller spillovers than small commercial operations *and* increase local income inequality is of special significance for Myanmar, where agricultural and land use policy have historically favored industrial-scale fish farm development, indicating that a reorientation of policy support toward smallholder-led development may be in order.

References

- Abdulai, A. (2006). Spatial integration and price transmission in agricultural commodity markets in sub-Saharan Africa. In A. Sarris & D. Hallam (Eds.), *Agricultural Commodity Markets and Trade: New Approaches to Analyzing Market Structure and Instability*. (pp. 163–186). Edward Elgar Publishers.
- Ahmed, M., & Lorica, M. (2002). Improving developing country food security through aquaculture development—lessons from Asia. *Food Policy*, 27(2), 125–141. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0306919202000076>
- Alison, E. H. (2011). *Aquaculture, fisheries, poverty and food security* (WorldFish Center Working Paper, 2011-65).
- Arthur, R., Béné, C., Leschen, W., & Little, D. (2013). *Fisheries and Aquaculture Aquaculture and Their Potential Roles in Development: An assessment of the current evidence*.
- Belton, B., Ahmed, N., & Murshed-e-Jahan, K. (2015). *Aquaculture, employment, poverty, food security and well-being in Bangladesh: A comparative study*. Penang, Malaysia.
- Belton, B., Filipski, M. J., & Hu, C. (2017). *Aquaculture in Myanmar: Fish Farm Technology, Production Economics and Management* (Feed the Future Innovation Lab for Food Security Policy No. Research Paper 52).
- Belton, B., Haque, M. M., & Little, P. (2012). Does Size Matter? Reassessing the Relationship between Aquaculture and Poverty in Bangladesh. *Journal of Development Studies*, 48(7), 904–922.
- Belton, B., Hein, A., Htoo, K., Kham, L. S., Phyo, S., & Reardon, T. (2017). The Emerging “Quiet Revolution” in Myanmar’s Aquaculture Value Chain. *Aquaculture*, (forthcomi).
- Belton, B., & Little, D. (2008). The Development of Aquaculture in Central Thailand : Domestic Demand versus Export-Led Production. *Journal of Agrarian Change*, 8(1), 123–143.
- Belton, B., & Little, D. (2011). Immanent and interventionist inland Asian aquaculture development and its outcomes. *Development Policy Review*, 29(4), 459–484. Retrieved from <http://onlinelibrary.wiley.com/doi/10.1111/j.1467-7679.2011.00542.x/full>
- Béné, C., Arthur, R., Norbury, H., Allison, E. H., Beveridge, M., Bush, S., ... Williams, M. (2016). Contribution of Fisheries and Aquaculture to Food Security and Poverty Reduction: Assessing the Current Evidence. *World Development*, 79, 177–196. <https://doi.org/10.1016/j.worlddev.2015.11.007>
- Bondad-Reantaso, M. R., & Subasinghe, R. P. (2013). *Enhancing the Contribution of Small-Scale Aquaculture to Food Security, Poverty Alleviation and Socio-economic Development* (Fisheries and Aquaculture Proceedings No. 31). (M. R. Bondad-Reantaso & R. P. Subasinghe, Eds.). Rome, Italy.
- Brummett, R. E., Gockowski, J., Pouomogne, V., & Muir, J. (2011). Targeting agricultural research and extension for food security and poverty alleviation: A case study of fish farming in Central Cameroon. *Food Policy*, 36(6), 805–814. <https://doi.org/10.1016/j.foodpol.2011.07.012>

- Diao, X., Hazell, P., & Thurlow, J. (2010). The role of agriculture in African development. *World Development*, 38(10), 1375–1383. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0305750X10001002>
- Dorward, A., Poole, N., Morrison, J., Kydd, J., & Urey, I. (2003). Markets, institutions and technology: missing links in livelihoods analysis. *Development Policy Review*, 21(3), 319–332.
- Edwards, P. (1999). *Aquaculture and Poverty: Past, Present, and Future Prospects of Impact*. Paper prepared for the Fifth Fisheries Development Donor Consultation, Rome, Italy 22-24 Feb 1999.
- Edwards, P., Little, D., & Demaine, H. (2002). Issues in rural aquaculture. In P. Edwards, D. Little, & H. Demaine (Eds.), *Rural aquaculture*. Wallingford, UK: CAB International. Retrieved from <https://books.google.com/books?hl=en&lr=&id=QFWrJVHLYAC&oi=fnd&pg=PA323&dq=edwards+aquaculture+poverty+past&ots=NPITZIXEjG&sig=scO5yCPIZ-DmLh9WVSDv9kik4EA>
- Fackler, P. L., & Goodwin, B. K. (2001). Chapter 17: Spatial Price Analysis. In B. Gardner & G. Rausser (Eds.), *Handbook of Agricultural Economics* (Vol. 1, pp. 972–1024). Elsevier Science B.V.
- FAO. (2016). *The State of World Fisheries and Aquaculture*. Rome, Italy.
- Filipski, M., Aboudrare, A., Lybbert, T. J., & Taylor, J. E. (2017). Spice Price Spikes: Simulating Impacts of Saffron Price Volatility in a Gendered Local Economy-Wide Model. *World Development*, 91(March), 84–99. <https://doi.org/10.1016/j.worlddev.2016.10.018>
- Filipski, M., Manning, D., Taylor, J. E., Diao, X., & Pradesha, A. (2013). *Evaluating the Local Economywide Impacts of Irrigation Projects* (IFPRI DP series No. 1247). International Food Policy Research Institute. Retrieved from <http://www.ifpri.org/sites/default/files/publications/ifpridp01247.pdf>
- Filipski, M., Taylor, J. E., Thome, K. E., & Davis, B. (2015). Effects of treatment beyond the treated: a general equilibrium impact evaluation of Lesotho's cash grants program. *Agricultural Economics*, 46(2015), 227–243. Retrieved from <http://onlinelibrary.wiley.com/doi/10.1111/agec.12153/full>
- Golden, C. D., Allison, E. H., Cheung, W. W. L., Dey, M. M., Halpern, B. S., McCauley, D. J., ... Myers, S. S. (2016). Nutrition: Fall in fish catch threatens human health. *Nature*, 534(7607), 317–320. <https://doi.org/10.1038/534317a>
- Haggblade, S., & Hazell, P. (1989). Agricultural technology and farm-nonfarm growth linkages. *Agricultural Economics*, 3(1989), 345–364. Retrieved from <http://www.sciencedirect.com/science/article/pii/016951508990008X>
- Haggblade, S., Hazell, P., & Dorosh, P. A. (2007). Sectoral growth linkages between agriculture and the rural nonfarm economy. In S. Haggblade, P. Hazell, & T. Reardon (Eds.), *Transforming the rural economy: Opportunities and threats in the developing world* (pp. 141–182). Johns Hopkins University Press. Retrieved from http://www.fsg.afre.msu.edu/responses/Haggblade_Nonfarm_book_Ch_7.pdf
- Hernandez, R., Belton, B., Reardon, T., Hu, H., Zhang, X., & Ahmed, A. (2017). The “Quiet Revolution” in the Aquaculture Value Chain in Bangladesh. *Aquaculture*, *forthcomin*.

Irz, X., Stevenson, J. R., Tanoy, A., Villarante, P., & Morissens, P. (2007). The equity and poverty impacts of aquaculture: Insights from the Philippines. *Development Policy Review*, 25(4), 495–516. <https://doi.org/10.1111/j.1467-7679.2007.00382.x>

Kassam, L., & Dorward, A. (2017). A comparative assessment of the poverty impacts of pond and cage aquaculture in Ghana. *Aquaculture*. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0044848616312170>

Leontief, W. W. (1986). *Input-output economics* (2nd ed.). New York: Oxford University Press.

Löfgren, H., Robinson, S., & Harris, R. L. (2002). *A Standard Computable General Equilibrium (CGE) Model in GAMS*. *Microcomputers in Policy Research*. IFPRI.

Mellor, J. (1986). Agriculture on the Road to Industrialization. In J. P. Lewis & V. Kallab (Eds.), *Development Strategies Reconsidered* (pp. 67–89). New Brunswick, NJ: Transaction Books for the Overseas Development Council. Retrieved from <http://krishikosh.egranth.ac.in/bitstream/1/2054734/1/MPKV-1175.pdf>

Robert, C. (2004). *Monte carlo methods*. Retrieved from <http://onlinelibrary.wiley.com/doi/10.1002/9781118445112.stat03876.pub2/full>

Singh, I., Squire, L., & Strauss, J. (1986). A survey of agricultural household models: Recent findings and policy implications. *The World Bank Economic Review*. Retrieved from <http://www.jstor.org/stable/3989948>

Taylor, J. E. (2013). *A methodology for local economy-wide impact evaluation (LEWIE) of cash transfers. Methodological guidelines for the From Protection to Production project*. (Vol. From Prote).

Taylor, J. E., & Filipiski, M. J. (2014). *Beyond Experiments in Development Economics: Local Economy-wide Impact Evaluation*. Oxford, UK: Oxford University Press.

Taylor, J. E., Filipiski, M. J., Alloush, M., Gupta, A., Rojas Valdes, R. I., & Gonzalez-Estrada, E. (2016). Economic impact of refugees. *Proceedings of the National Academy of Sciences of the United States of America*, 113(27), 7449–53. <https://doi.org/10.1073/pnas.1604566113>

Thome, K., Filipiski, M., Kagin, J., Taylor, E., & Davis, B. (2013). Agricultural Spillover Effects of Cash Transfers: What Does LEWIE Have to Say? *American Journal of Agricultural Economics*, 95(5), 1338–1344.

Appendix A: LEWIE Model Statement

Table A1. Set, Subset and Mapping Names Used in Model Statement

Sets			
g	commodities	f	factors
h or hh	households		
h or hh	households		
Subsets			
gtv	Goods locally tradable	fk	Fixed factors
gtz	Goods traded in outside markets	ft	Locally tradable factors
gp	Locally produced goods	ftw	Factors traded in outside markets
gag	Agricultural goods	fpurch	Purchased variable inputs
gnag	Nonagricultural goods		
Mappings			
maphv(h,v)	Mapping of households to cluster		

Table A2. Commodities, Factors, Households

Commodities	
Crop	Crops produced or consumed within the cluster
Meat	Meat produced or consumed within the cluster
Fish	Fish produced or consumed within the cluster
Fish seed	Fish eggs, hatchlings or fingerlings produced locally
Retail	Local retailers in the cluster
Services	Local Services provided within the cluster
Production	All other local production, such as crafts or food processing
Outside good	Any commodity purchased outside the local economy
Factors	
Labor	Labor (family and hired receiving wage in cash or kind)
Land	Crop land or ponds

Capital	Capital
Input	Purchased production inputs (feeds and fertilizers)
Households	
Small fish farm	Fish farms with total pond area <10 acres
Large fish farms	Fish farms with total pond area >10 acres
Nurseries	Fish farms specialized in nursery activity (no growout)
Crop farms	Crop farms
Non-farm	All households with no farming activity (fish or crop), including landless farm workers.

Table A3. Variable Names Used in Model Statement

VARIABLES			
Values		Consumption and income	
PV(g,v)	price of a good at the cluster level	QC(g,h)	quantity of g consumed by h
PZ(g)	price of a good at the regional level	Y(h)	nominal household income
PH(g,h)	price as seen by household h (=PV or PZ)	RY(h)	real household income
PVA(g,h)	price of value added net of intermediate inputs	CPI(h)	consumer price index
R(g,f,h)	rent for fixed factors	TROUT(h)	transfers given by a household of others
WV(f,v)	wage at the cluster level	SAV(h)	household savings
WZ(f)	wage at the regional level	EXPROC(h)	household expenditures out of the region
Production		Trade	
QP(g,h)	quantity produced of a good by a household	HMS(g,h)	household marketed surplus of good g
FD(g,f,h)	factor demand of f in production of g	VMS(g,v)	cluster marketed surplus of good g
ID(g,gg,h)	intermediate demand for production of g	ZMS(g)	Regional marketed surplus of a good
QVA(g,h)	quantity of value added created	HFMS(f,h)	factor marketed surplus from the household
HFD(f,h)	factor demand in the household	VFMS(f,v)	factor marketed surplus out of the cluster
HFSUP(f,h)	labor supply from the household (elastic endowment)	ZFMS(f)	factor marketed surplus out of the region

Table A4. Parameter Names Used in Model Statement (GAMS)

PARAMETERS			
Production		Consumption	
a(g,h)	Shift parameter in CD production function	alpha(g,h)	consumption share parameters in the LES
beta(g,f,h)	Factor share parameters (CD exponents)	cmin(g,h)	minimal consumption in the LES
vash(g,h)	Value-added share of output	exinc(h)	exogenous income of household
idsh(gg,g,h)	Intermediate input share	vmsfix(g,v)	fixed marketed surplus at the village level
fixfac(g,f,h)	Fixed factor endowments	Transfers	
vfmsfix(f,v)	Factors fixed at the local level (family, hired labor)	troutsh(h)	share of transfers in household expenditures
endow(f,h)	Household factor endowments	exprocsh(h)	share of expenditures outside of cluster
hfsupzero(f,h)	Initial labor supply	savsh(h)	share of income saved
hfsupel(f,h)	Factor supply elasticity	trinsh(h)	share of total transfers received by a given household
		For Experiments	
		fsim(g,f,h,sim)	Exogenous change in factor endowment in the simulation (land)
pibudget(g,h)	Liquidity constraint on inputs		
pibsh(g,h)	Share of pibudget to good g		

Table A5. Equation Definitions

Equation Name	Description
* prices	
EQ_PVA(g,h)	prive value added equation
EQ_PH(g,h)	market price as seen from household h
* production	
EQ_FDCOBB(g,f,h)	factor demands cobb douglas
EQ_QVACOBB(g,h)	quantity VA produced cobb douglas
EQ_QP(g,h)	quantity produced from QVA and ID
EQ_ID(gg,g,h)	quantity of ID needed for QP
* consumption	
EQ_QC(g,h)	quantity consumed
* income	
EQ_Y(h)	full income constraint for the household
EQ_CPI(h)	consumer price index equation
EQ_RY(h)	real household income equation
* transfers	
EQ_TRIN(h)	inter household transfers in (received)
EQ_TROUT(h)	interhousehold transfers out (given)
* exogenous expenditures	
EQ_SAV(h)	savings (exogenous rate)
EQ_EXPROC(h)	expenditures outside of the zoi (exogenous rate)
* goods market clearing	
EQ_HMKT(g,h)	qty clearing in each household
EQ_VMKT(g,v)	market clearing in the village
EQ_ZMKT(g)	market clearing in the zoi
EQ_VMKTfix(g,v)	price definition in the cluster
EQ_ZMKTfix(g)	price definition in the zoi

*** factor market clearing**

EQ_HFD(f,h)	total household demand for a given factor
EQ_FCSTR(g,f,h)	fixed factors constraint
EQ_HFSUP(f,h)	household elastic supply
EQ_HFMKT(f,h)	tradable factor clearing in the household
EQ_VFMKT(f,v)	tradable factors clearing in the village
EQ_ZFMKT(f)	tradable factor clearing in the zoi
EQ_VFMKTfix(f,v)	wage determination for tradable factors clearing in the village
EQ_ZFMKTfix(f)	wage determination for tradable factors clearing in the zoi

Table A6. Equations in the Model

Name	Equation
<u>1) HOUSEHOLD EQUATIONS</u>	
Price Block	
EQ_PH(g,h)..	$PH_{g,h} = [PZ_g]_{g \in gtz \cup gtw} + \left[\sum_{v maphv(h,v)} PV_{g,v} \right]_{g \in gtv}$
EQ_PVA(g,h)..	$PVA_{g,h} = PH_{g,h} - \sum_{ga} idsh_{ga,g,h} \times PH_{ga,h}$
Production Block	
EQ_QVACOBB(g,h)..	$QVA_{g,h} = a_{g,h} \times \prod_f (FD_{g,f,h})^{\beta_{g,f,h}}$
EQ_FDCOBB(g,f,h)	$[R_{g,f,h}]_{f \in fk} + [WZ_f]_{f \in ftz} + \left[\sum_{v maphv(h,v)} WV_{f,v} \right]_{f \in ftv} = \frac{PVA_{g,h} \times QP_{g,h} \times \beta_{g,f,h}}{FD_{g,f,h}}$
EQ_QP(g,h)	$QP_{g,h} = QVA_{g,h} / vash_{g,h}$
EQ_ID(gg,g,h)..	$ID_{ga,g,h} = QP_{g,h} \times idsh_{ga,g,h}$

Consumption and income block

EQ_QC(g,h)..	$QC_{g,h} = \frac{\alpha_{g,h}}{PH_{g,h}} \times \left(Y_h - TROUT_h - SAV_h - EXPROC_h - \sum_{ga} PH_{ga,h} \times cmin_{ga,h} \right) + cmin_{g,h}$
EQ_Y(h)..	$Y_h = \sum_{g,fk} (R_{g,fk,h} \times FD_{g,fk,h}) + \sum_{g,ftz} WZ_{ftz} \times HFSUP_{ftz,h} + \sum_{ftv} \sum_{v maphv(h,v)} WV_{ftv,v} \times HFSUP_{ftv,h} + \sum_{ftw} WZ_{ftw} \times HFSUP_{ftw,h} + exinc_h$
EQ_TROUT(h)..	$TROUT_h = troutsh_h \times Y_h$
EQ_EXPROC(h)..	$EXPROC_h = exprocsh_h \times Y_h$
EQ_SAV(h)..	$SAV_h = savsh_h \times Y_h$
EQ_CPI(h)..	$CPI_h = \sum_g PH_{g,h} \times \alpha_{g,h}$
EQ_RY(h)..	$RY_h = \frac{Y_h}{CPI_h}$

2) MARKET CLOSURE:

Market clearing block for commodities

EQ_HMKT(g,h)..	$HMS_{g,h} = QP_{g,h} - QC_{g,h} - \sum_{ga} ID_{g,ga,h}$
EQ_VMKT(g,v)..	$VMS_{g,v} = \sum_{h maphv(h,v)} HMS_{g,h}$
EQ_ZMKT(g)..	$ZMS_{g,v} = \sum_v VMS_{g,v}$
EQ_VMKTfix(gtv,v)..	$VMS_{gtv,v} = vmsfix_{gtv,v}$
EQ_ZMKTfix(gtz)..	$ZMS_{gtz} = zmsfix_{gtz}$

Market clearing block for factors

EQ_HFV(f,h)..	$HFD_{f,h} = \sum_g FD_{g,f,h}$
EQ_FCSTR(g,fk,h)..	$FD_{g,fk,h} = fixfac_{g,fk,h}$
EQ_HFMKT(ft,h)..	$HFMS_{ft,h} = HFSUP_{ft,h} - \sum_g FD_{g,ft,h}$
EQ_HFSUP(ft,h)..	$\frac{HFSUP_{ft,h}}{hfsup_{ft,h}^0 + hfsnewref_{ft,h}} = \left[\sum_{d maphd(h,d)} (WD_{ft,d})^{\zeta_{ft,h}} \right]_{f \in ftd} + \left[(WZ_{ft,d})^{\zeta_{ft,h}} \right]_{f \in ftz \cup ftw}$
EQ_VFMKT(ft,v)..	$DFMS_{g,d} = \sum_{h maphd(h,d)} HFMS_{g,h}$
EQ_ZFMKT(ft)..	$ZFMS_{ft} = \sum_v VFMS_{ft,v}$
EQ_VFMKTFIX(ftv,v)..	$VFMS_{ftd,d} = vfmsfix_{ftv,v}$
EQ_ZFMKTFIX(ftz)..	$ZFMS_{ftz} = zfmsfix_{ftz}$
For simulations with a budget constraint	
EQ_FDCOBB(g,f,h) (only for purchased factors)	$FD_{g,f,h} \times WZ_f = pibudget_{g,h}$