

NICARAGUA, THE FOOD CRISIS, AND THE FUTURE
OF SMALLHOLDER AGRICULTURE

By

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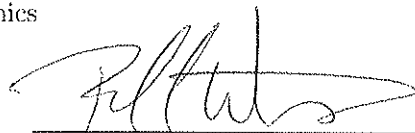
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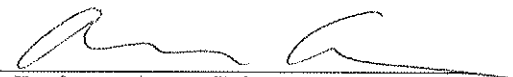
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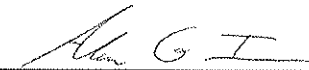
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ABSTRACT

The 2007-08 world food crisis signaled the necessity of increasing global food supply and revived a long-standing debate surrounding the relationship between productivity/profitability and the size of agricultural landholdings. At the center of the debate, Oxford University's Paul Collier challenged years of empirical work supporting an inverse relationship between farm size and productivity/profitability in developing countries, and called for the increasing implementation of large-scale commercial agriculture and the utilization of scale economies in skills and technology, finance and access to capital, and the organization and logistics of trading. Consisting of three essays, the first two essays of the dissertation seek to empirically address the questions raised by examining the case of Nicaragua. Motivated by the results, the third and final essay then undertakes a theoretical exploration of the efficiency of inequality in the distribution of agricultural landholdings in the wake of the radical restructuring of global agri-food systems.

In the first essay, we employ Markov chain methods within an information-theoretic framework so as to provide a refined examination of structural transformation in Nicaragua's agricultural and livestock sector. With stability and perhaps growth as a class of producers, the results indicate that small-scale agriculture does demonstrate a capacity to persist in a globalizing world. In response to these results, in the second essay, we develop a four-stage empirical framework so as to simultaneously investigate the existence and explanation of a robust relationship between farm size and productivity/profitability in Nicaragua. The

results of the analysis suggest that labor market imperfections are ostensibly the driving force behind the observed inverse relationship. The third essay, then, outlines an agent-based computational model to explore the efficiency of inequality in the distribution of agricultural landholdings in an agrarian economy characterized by credit and labor market imperfections as well as both traditional and modern value chains. The model illustrates that, in the presence of relatively high fixed costs associated with meeting the quality standards of the modern value chain, a potential equity/efficiency tradeoff emerges thereby suggesting that the pursuit of redistributive land reform may require supplemental policy measures and/or *ex ante* empirical assessment to determine scope limitations.

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CHAPTER 1

INTRODUCTION

In the face of rising food prices, the Food and Agriculture Organization of the United Nations (FAO) estimated that the number of chronically hungry people increased by 75 million in 2007 alone, which brought the total number of undernourished worldwide to 923 million. Before the 2007-08 world food price crisis, steady progress had been achieved toward the hunger-related Millennium Development Goals, but the rising prices brought about a reversal in that trend in the Asia/Pacific, Latin America/Caribbean, Near East-/North Africa, and Sub-Saharan African regions (FAO 2008). Termed the “perfect storm” in the United Nations’ *World Economic Situation and Prospects 2009*, the crisis revived a long-standing debate regarding productivity/profitability and the size of agricultural landholdings. At the center of the debate, Oxford University’s Paul Collier challenged years of empirical work supporting an inverse relationship between farm size and productivity/profitability in developing countries, and called for the increasing implementation of large-scale commercial agriculture and the utilization of scale economies in skills and technology, finance and access to capital, and the organization and logistics of trading. Consisting of three essays, the first two essays of the dissertation seek to empirically address the questions raised by examining the case of Nicaragua. Motivated by the results, the third and final essay then undertakes a theoretical exploration of the efficiency of inequality in the distribution of agricultural landholdings in the wake of the radical restructuring of global agri-food systems.

In the context of wider debate regarding the impact of globalization and/or liberalization on smallholder agriculture in developing countries, the first essay explores, for the case of Nicaragua, recent trends in the distribution and use of agricultural landholdings, as well as the role agricultural policy and other key factors have played in shaping those trends. Accordingly, two basic research questions are put forth: First, what is the future of smallholder agriculture in Nicaragua? More specifically, what are the relative probabilities of expansion, contraction, and exit of small-, medium-, and large-scale producers? Does such size-oriented transformation entail an analogous transformation in land use or output composition? Second, what role do policy/environmental variables play in preventing or facilitating such structural transformation in the agricultural sector? So as to fully understand the contemporary situation facing Nicaraguan agricultural producers, the analysis begins by presenting an in-depth historical narrative of the economic and political factors that have shaped the development of agricultural production in Nicaragua, particularly as it pertains to smallholders. Then, with the historical information in hand and employing Markov chain methods within an information-theoretic framework, the analysis uses nationally-representative, LSMS-type data for the years 1998, 2001, and 2005 to provide a refined examination of post-Sandinista structural transformation while paying special attention to specific policy/environmental variables. With stability and perhaps growth as a class of producers, the results indicate that small-scale agriculture does demonstrate a capacity to persist in a globalizing world. Further, whereas transformation in land use or output composition is quite uncommon among small- and medium-scale producers, there manifests a tendency toward specialization among larger-scale producers. Finally, as the pace of structural transformation appears relatively sensitive to changes in input and output prices, the results should be interpreted in light of increasing price volatility.

In response to the results of the first essay, the second essay is motivated by the following fundamental question: Why is the proportion of producers operating smallholdings persistently large and seemingly rising? Lipton (2009, 2010), citing farm size trends in a wide array of developing countries, considered a multitude of explanations for this

question (e.g. rural population growth, technological change, rising share of rural income from off-farm activities, etc.), but came to suggest that it cannot be reasonably answered except by the aforementioned inverse relationship. In the second essay, then, in a thorough review of the relevant literature, we first critically examine the widespread empirical finding of an inverse relationship between farm size and productivity/profitability in developing countries, a phenomenon, it is contended, most reasonably attributed to labor market imperfections or (technical and/or allocative) efficiency differences between small and large producers. After revisiting Nicaragua's nationally-representative LSMS-type panel data, we then elaborate upon a four-stage empirical framework so as to simultaneously investigate the existence and explanation of a robust relationship between farm size and productivity/profitability in Nicaragua's agricultural and livestock sector. Finally, in turning to the results of the analysis, it appears that while technical and allocative efficiency differences frequently exert a statistically significant impact on alternative productivity/profitability indicators across different samples, the explanatory power of these variables is evidently insufficient to rule out labor market imperfections as the driving force behind the observed inverse relationship.

With respect to the third essay, agricultural value chains in developing countries have undergone considerable change as a result of dietary diversification as well as the food-related trade and foreign direct investment growth that has accompanied liberalization and/or globalization. The increasing prominence of export horticulture, the rapid rise of supermarkets, and the proliferation of grades and standards have heightened the need for vertical coordination and resulted in the creation of modern procurement systems, the stringent quality standards of which credit-constrained, small-scale producers typically find difficult to meet. Even though the balance of empirical evidence suggests that, due to a relatively low shadow price of labor, smaller-scale producers continue to possess a distinct productivity advantage in labor-abundant economies, the radical restructuring of global agri-food systems has raised questions as to whether redistributive land reform remains a viable policy option in efforts aimed toward meeting aggressive agricultural production

targets. Incorporating insights, then, from the first two essays, the third essay develops an agent-based computational model to explore the efficiency of inequality in the distribution of agricultural landholdings in an agrarian economy characterized by credit and labor market imperfections as well as both traditional and modern value chains. The model illustrates that, in the presence of relatively high fixed costs associated with meeting the quality standards of the modern value chain, a potential equity/efficiency tradeoff emerges thereby suggesting that the pursuit of redistributive land reform may require supplemental policy measures and/or *ex ante* empirical assessment to determine scope limitations.

Overall, then, the primary objective of the dissertation is to explore, in a developing country context, the efficiency of inequality in the distribution of agricultural landholdings in the presence of high-value markets. While this objective is not explicitly addressed until the final essay, a comprehensive understanding of structural transformation in developing country agriculture, as well as its driving forces (i.e. the relationship between farm size and productivity/profitability), appears integral to the theoretical examination of the research question, which is the precise rationale for the antecedent empirical essays. Importantly, however, each essay in and of itself makes a discernible contribution to the relevant literature. Regarding the first essay, employing Markov chain methods within an information-theoretic framework permits a particularly refined analysis of structural transformation, yet it is an approach that has evidently not witnessed application in a developing country setting. With respect to the second essay, a large body of empirical work has amassed in exploration of the aforementioned inverse relationship, but to date no such work has simultaneously explored the relative explanatory power of the two leading explanations: asymmetric market imperfections and efficiency differences between small and large agricultural producers. Finally, the third essay represents the primary contribution of the dissertation as theoretical examination of the relationship between the distribution of agricultural landholdings and aggregate outcomes of interest (e.g. welfare, profit, output, etc.) has yet to incorporate, at least in a rigorous manner, the critical intermediating role of modern value chains.

CHAPTER 2

STRUCTURAL TRANSFORMATION

AND SMALLHOLDER AGRICULTURE

2.1 Introduction

Agriculture in the developing world is largely characterized by a predominance and persistence of smallholders. Nagayets (2005), defining smallholders as those producers that cultivate less than two hectares of land, estimated that such actors operate 85 percent of the 525 million farms worldwide.¹ Whereas the vast majority of small-scale producers are found in Asia (87 percent) and Africa (8 percent),² smallholders are by no means confined to these regions. For example, on average, approximately 63 percent of landholdings in Central America and the Caribbean are cultivated by smallholders (Eastwood et al. 2010, 3330). Moreover, historical trends suggest that small-scale agricultural production, at least in developing nations, will remain prevalent in the coming decades. While in a cross-country setting there is indeed a positive association between mean farm size and GDP per capita,³ this masks international divergences in mean farm sizes. As the more advanced regions of Europe and North America have witnessed increasing mean farm sizes over the past century, the less advanced regions of Africa, Asia, and (to a lesser extent) South America

¹The estimate is based on the 470 million farms with available data.

²See Figure 1 in Nagayets (2005).

³Using weighted least squares, Eastwood et al. (2010) found an elasticity of unity (p -value < 0.01) when regressing the natural log of mean farm size on the natural log of GDP per capita for a sample of fifty countries. Further, note the justification provided therein regarding the use of mean farm size as an indicator of the size distribution of farms.

have seen overall decreases.⁴ Accordingly, “changes in GDP per capita are only weakly associated with changes in farm size” (Eastwood et al. 2010, 3333).

So, what explains the above empirical findings? Smallholder resilience to price slumps (Chayanov 1966), a “functional” role as a source of cheap labor (De Janvry 1981), and the unsuitable nature of certain soil types and conditions to large-scale mechanized farming (Wiggins 2009) have all been well-received explanations. However, perhaps the most familiar and celebrated explanation is that of an inverse relationship between farm size and productivity in developing country agriculture.⁵ Lipton (2010), for example, argued that “a large majority of empirical work in developing countries finds that output per hectare-year has an inverse relationship (IR) to farm area, in contrast to the direct relationship (DR) often found in developed countries” (1399). Thus, in developing countries, “smaller scale either is becoming relatively more advantageous to farmers or has for some time been so (due to the IR), while distortions concealing that fact have decreased” (1403). As development typically brings rising fixed capital to labor ratios, Lipton contended that the latter explanation is more likely. Collier (2008) as well as Collier and Dercon (2009), however, emphasized that with further liberalization and the emergence of supermarkets comes a growing need to overcome persistently high transaction costs in agricultural markets in developing countries (e.g. in product standardization, certification, etc.). Accordingly, economies of scale in skills and technology, finance and access to capital, and the organization and logistics of trading, marketing, and storage may come to outweigh any diseconomies of scale. Thus, with the erosion of the IR, great care should be taken when extrapolating historical trends.

In an attempt to address the preceding arguments, the following analysis focuses on the case of Nicaragua. From the colonial era, through the Somoza years, and to the Sandinista revolution, Nicaragua underwent repeated and extensive land redistribution that typically led to the increasing concentration of land and marginalization of smallholders.

⁴See Figure 1 in Eastwood et al. (2010).

⁵See Barrett et al. (2010) for a recent review of the literature on the inverse relationship.

With the election of Violeta Chamorro in 1990 and the onset of structural adjustment, Nicaragua witnessed dramatic austerity measures, trade liberalization, and privatization, which unleashed market forces and created room for “voluntary” shifts in farmland. Perhaps most interestingly, however, the re-election of Daniel Ortega in 2006 marked the placement of smallholder agriculture at the center of Nicaragua’s development strategy and, therefore, signals the increasing relevance of the aforementioned arguments.

Within this context, two basic research questions are put forth: First, what is the future of smallholder agriculture in Nicaragua? More specifically, what are the relative probabilities of expansion, contraction, and exit of small-, medium-, and large-scale producers? Does such size-oriented transformation entail an analogous transformation in land use or output composition? Second, what role do policy/environmental variables play in preventing or facilitating such structural transformation in the agricultural sector? So as to fully understand the contemporary situation facing Nicaraguan agricultural producers, the analysis begins by presenting an in-depth historical narrative of the economic and political factors that have shaped the development of agricultural production in Nicaragua, particularly as it pertains to smallholders. Then, with the historical information in hand and employing Markov chain methods within an information-theoretic framework, the analysis uses nationally-representative, LSMS-type data for the years 1998, 2001, and 2005 to provide a refined examination of post-Sandinista structural transformation while paying special attention to specific policy/environmental variables.

First, Nicaragua’s agricultural and livestock sector is found to be characterized by a net entry of producers, which is largely due to overall low probabilities of exit. Moreover, entry that occurs is almost exclusively into beans and maize production and typically at a small-scale. As such, while smallholders witness relatively low probabilities of expansion, a low propensity to exit coupled with new small-scale entrants implies a definitive persistence of smallholder agriculture. Second, given the high (low) probabilities associated with transition from (to) production on an intermediate scale, the land distribution exhibits a moderate tendency toward bifurcation, which would appear to obscure any immedi-

ate relationship between operational landholdings and land productivity. Third, whereas transformation in land use or output composition is quite uncommon among small- and medium-scale producers, there manifests a tendency toward specialization among larger-scale producers, primarily to that of livestock production. Such changes in output composition, at the very least, point toward a dynamism to which smallholders are compelled to adapt. Finally, the pace of structural transformation appears relatively sensitive to changes in input and output prices. Accordingly, the aforementioned results should be interpreted in light of increasing price volatility.

2.2 The Nicaraguan Smallholder in Historical Context

“The development of capitalism in Nicaragua was first expressed and has remained concentrated in that country’s agricultural sector and was based almost exclusively on the expansion of agroexport production” (Enríquez 1991, 18). If, historically, agroexport production has been the engine of the economic development of Nicaragua, agricultural policy has been situated at the wheel, attempting to accommodate and stimulate agroexport production at every turn. The environment in which smallholder production has been forged is adequately viewed as the by-product of the interaction of these two forces. As the Sandinista revolution represents a historical break in the developmental trajectory of Nicaragua, the following historical narrative of the economic and political factors shaping smallholder production in Nicaragua is divided into three distinct components: (1) the pre-Sandinista era and the rise of agroexport; (2) the Sandinista revolution and the foreign exchange constraint; and (3) the post-Sandinista years, structural adjustment, and the return of Daniel Ortega.

2.2.1 The Pre-Sandinista Era and the Rise of Agroexport

In the sixteenth century, Spanish colonization of Nicaragua and the subsequent slave trade decimated the population, which led to acute labor shortages. Abandoning labor-intensive crop cultivation, the Spanish crown authorized the introduction of livestock production in 1527, which became a widespread and lucrative commercial venture by the

end of the century. Accordingly, cattle ranching consumed ever-greater quantities of land that was traditionally farmed communally by the indigenous population for subsistence production. To ensure minimal labor requirements were met, the indigenous population, increasingly farming small, individual plots of land, was subsequently tied and compelled to pay tribute to the large estates. This “*hacienda-type*” land tenure came to be known as the *latifundio-minifundio* complex and was the defining characteristic of colonial agricultural production (Biderman 1983, 9; Biondi-Morra 1993, 21; Enríquez 1991, 19-21).

Out of the *latifundio-minifundio* complex materialized an oligarchy of landed descendants of the colonial order. As the landed classes came to seek more freedom from Spain’s monopolization of the colonies’ trade relations, the struggle for independence was waged and resulted in Nicaragua becoming an independent republic in 1838. Due to conflicting elements within the evolving bourgeoisie (i.e. the “conservative” cattle ranchers of Granada and the “liberal” coffee producers of León), the Nicaraguan economy remained relatively stagnant until 1893 and the presidency of Liberal José Santos Zelaya. The Zelaya presidency signaled the overthrow of the traditional oligarchy and a drive to place coffee production at the center of the agroexport sector (Biondi-Morra 1993, 22; Enríquez 1991, 23-31; Paige 1984, 4-6). To remedy persistent economic stagnation and ensure an adequate supply of land and labor for coffee production, the Zelaya government: (1) passed land reorganization laws and subjected to expropriation those peasants who could not present land titles to prove their ownership; (2) offered land grants to foreigners that were willing to undertake coffee production; and (3) enacted the vagrancy laws that tied available labor to the land (Biderman 1983, 11-12; Enríquez 1991, 26-30). The cumulative result of these policies was a further concentration of land ownership and the dispossession, marginalization, and/or proletarianization of the peasantry. As the Zelaya presidency came to an abrupt halt in 1909, Nicaragua’s agricultural sector saw no marked advances for another fifty years.

The historical trajectory of increasingly concentrated land ownership was accelerated during the reign of the Somozas (1937-1979). Turning away from the simple appropriation

of Nicaragua's already existing wealth, by the 1950s the Somoza regime began attempting to consolidate power via economic growth by using the state to encourage the diversification and modernization of agriculture. The ensuing policies sought to exploit rising global demand for cotton and were almost exclusively channeled to a few groups of large, export-oriented, capitalist producers. The policies included: (1) extensive infrastructural improvements, which facilitated access to land; (2) expanded credit, favorable exchange rates, and modified tariff and pricing policies, which encouraged productivity-enhancing investments; and (3) publicly-subsidized provision of irrigation and research as well as storage, processing, and marketing facilities (Biderman 1983, 13-14).

Largely successful, during the 1960s Nicaragua experienced growth rates in real per capita income that were double those of Central America as a whole (Williams 1986, 166) and witnessed a rate of agricultural expansion that was the highest in the world (Paige 1984, 1). Importantly, the economic success was largely based on cotton export. By the 1954-1955 harvest, the area planted with cotton was roughly five times what it had been four years prior. In addition, cotton came to displace coffee as Nicaragua's main export crop as its export value increased from \$2 million in 1950 to \$66 million in 1965 (Biondi-Morra 1993, 24). While one of the most dynamic periods of Nicaragua's economic history, the cotton boom led to a marginalization of food production and concentration of land. As large, export-oriented producers received the majority of financing and technical assistance, smallholders were forced to cultivate progressively smaller plots or migrate to lower quality land. Thus, throughout the 1960s, growth rates for primary food crops slowed and by the end of the decade production was largely stagnant (Ryan 1995, 56-57).

As the cotton boom lost steam in the late 1960s, Nicaragua began focusing on the export of chilled boneless beef to the United States. Similar to the cotton boom, the Somoza government played a distinct role in furthering accumulation by (1) coordinating imports of high-grade breeding stock; (2) providing favorable credit terms and technical assistance for cattle improvement programs; (3) financing slaughterhouses, meat-packing plants, and dairy facilities; and (4) organizing new marketing arrangements for exporting

beef and related by-products. While the above policies promoted intensification and modernization, beef production remained largely traditional and extensive in nature. As such, the promotion of beef exports led to the doubling of area used for pasture between 1960 and 1979, which once again displaced many small food producers from cattle producing regions (Biondi-Morra 1993, 26-27).

From 1963 to 1978, the average farm size rose from 62 to 78 *manzanas*⁶ (Baumeister and Fernández 2005, 15). Looking to Table 2.1, it is evident that the smallest producers (those owning less than 10 *manzanas*) controlled just 2.1 percent of cultivated land in 1978, down from 3.5 percent in 1963. Conversely, those producers owning 10-200 *manzanas* witnessed a continual expansion in their share of total farmland, increasing from 37.7 percent in 1963 to 45.5 percent in 1978. Lastly, producers owning greater than 200 *manzanas* saw their shares consistently hover around 55 percent throughout the same period. With the persistent concentration of land, tenure insecurity, and landlessness that resulted from the cotton and beef export booms, rural tension mounted. As a result of the perceived unrest, during the 1960s and 1970s, the Somoza regime instituted a series of reform projects in an attempt to pacify the peasantry. The *Instituto Agrario de Nicaragua* (IAN) (founded in 1963), among other acts, implemented a land titling program and a land colonization program, both of which had extremely limited impacts. The land titling program only reached 16,500 families whereas the colonization program only assisted 2,651 families. Similarly, the *Instituto de Bienestar Campesino* (INVIERNO) (founded in 1975), which situated agricultural lending as its primary objective, only allocated 8.2 million *córdobas* (\$1.2 million) of credit across a total of 2,882 clients. Further, INVIERNO charged exorbitant 18 percent interest rates on their loans, thereby increasing the indebtedness of loan recipients, driving them to seek supplementary employment in the agroexport sector, and, thus, strengthening the already existing agrarian structure (Enríquez 1991, 50-52).

⁶1 *manzana* = 0.7 hectares

Table 2.1: Evolution of Ownership Landholdings in Nicaragua (1963-2001) (% of total area of farmland)

Sector	1963	1971	1978	1982	1984	1986	1988	2001
<i>Private</i>	100.0	100.0	100.0	74.0	63.5	60.9	60.3	95.6
<10	3.5	2.9	2.1	2.1	1.6	1.6	1.6	4.5
10-50	11.2	13.3	15.4	15.3	6.9	7.2	7.2	20.0
50-200	26.5	28.4	30.1	29.5	29.6	29.9	30.0	36.6
200-500	17.6	21.0	16.2	14.7	12.6	12.4	12.0	18.0
>500	41.2	34.5	36.2	12.5	12.7	9.9	9.4	16.5
<i>Reformed</i>	0.0	0.0	0.0	26.0	36.5	39.1	39.7	4.4
State	0.0	0.0	0.0	20.1	18.8	13.4	12.4	0.4
Collective	0.0	0.0	0.0	5.8	17.8	21.1	23.4	4.0
<i>Total</i>	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: The 1963-1978 as well as the 2001 data are taken from Baumeister and Fernández (2005, 14-15). The 1982-1988 data are taken from Spoor (1995, 55).

Note: Due to abandoned land, the area under state and collective cultivation for the years 1986 and 1988 does not completely constitute the reformed sector.

The effect of the Somoza years on smallholder production was eloquently summed up by Biderman (1983):

The combined effect of a diminishing quantity and quality of accessible land, lack of access to credit and state-subsidized inputs and low support prices made the earnings of small food producers extremely low. . . .

. . . Overall, the state's half-hearted and poorly funded efforts to respond to the plight of small producers . . . contrasted sharply with its subsidized accumulation-oriented activities on behalf of large capitalist producers . . . the reformist programs . . . were very limited, and were largely oriented not towards accumulation but towards legitimation. . . . Moreover, the poverty and immiseration of semiproletarian small producers and landless workers continued to be accentuated by the dynamism of the agrarian [*sic*] capitalist sector. . . . Faced with these persisting contradictions, which mild reformism failed to overcome, the Nicaraguan state resorted increasingly to repression and counterinsurgency. (20-24)

In short, the advancement of agroexport production that occurred during the colonial era, the Zelaya presidency, and the Somoza years was largely at the expense of small-scale food production and resulted in a highly concentrated distribution of land, which led to political instability and paved the way for the Sandinista revolution.

2.2.2 The Sandinista Revolution and the Foreign Exchange Constraint

The *Frente Sandinista de Liberación Nacional* (FSLN or Sandinistas) overthrew Anastasio Somoza Debayle in July of 1979. Informed ideologically by Marxism, Christianity, and the nationalist thought of Augusto César Sandino, the Sandinistas sought a revolutionary transformation of Nicaragua's economic, political, and social relations. Given the nature of Nicaragua's economy, agrarian reform was of the utmost importance to the Sandinistas. "Beginning from a position that emphasized state production, the FSLN would gradually be forced by political factors to accept the growth of 'lower' and more 'backward' productive forms [i.e. smallholder production]. Throughout, their policy would reflect the tensions that have historically marked Marxian socialist thinking on the peasant question" (Ryan 1995, 90-91). Thus, the Sandinista position on agrarian reform underwent substantial changes throughout the 1980s, which reflected a certain tradeoff between economic necessity and political survival.

Immediately upon taking office, the Sandinistas instituted the first major phase of agrarian reform where, under Decrees 3 (July 20, 1979) and 38 (August 8, 1979), the landholdings of Somoza and his allies were confiscated (approximately 2,000 farms and 20 percent of Nicaragua's agricultural land). As the *Somocista* properties were typically modern, large-scale, export-oriented operations, this act represented a significant reduction of privately owned large landholdings since these farms accounted for 43 percent of all land held in properties larger than 500 *manzanas*. Importantly, the land was to remain in direct control of the state and form what was known as the *Area de Propiedad del Pueblo* (APP) (Biondi-Morra 1993, 40; Luciak 1987, 116). There were three primary justifications for continued state control: (1) the Sandinistas needed to ensure continued generation of foreign exchange as a significant portion of the land was export-oriented; (2) transfer of the land into private hands may have led to fragmentation, which would endanger existing economies of scale and the possibility of intensifying technological development in the future; and (3) they feared that the distribution would lead to increasing land takeovers and, thus, threaten national unity (Deere and Marchetti 1985, 79-82). It is crucial to note

here that peasants and small farmers were largely neglected by these policies, which was at odds with pre-revolution promises (Ryan 1995, 92).

On July 19, 1981 with the announcement of the *Ley de Reforma Agraria* (Agrarian Reform Law), the Sandinistas ushered in a second major phase of agrarian policy. The law had three objectives: (1) to bring idle or unused private sector land into production; (2) to satisfy peasant demands for secure access to land; and (3) to calm the growing fears of the export-oriented bourgeoisie and, thus, ensure the continued generation of foreign exchange. Under the law, any abandoned land was subject to redistribution by the government. All idle or underutilized land on estates exceeding 350 hectares in the Pacific region and 700 hectares in the rest of the country was subject to expropriation. Further, in an attempt to end the exploitation of poor farmers by absentee landlords, for plots larger than 35 hectares in the Pacific region and 70 hectares in the rest of the country, any land farmed under pre-capitalist relations of production (i.e. sharecropping or labor service arrangements) could be confiscated. While the principal beneficiaries were to be peasants who had been farming under rental arrangements of any type, smallholders with insufficient land, landless workers, or urban residents that wished to produce basic grains, the agrarian reform land was to be largely distributed in the form of production cooperatives to prevent the fragmentation of landholdings and allow continued control by the state (Collins 1985, 87-94; Deere and Marchetti 1985, 91-92).⁷

Problematically, many cooperatives were formed hastily without technical assistance and, after experiencing credit difficulties, subsequently dissolved. Nearly 30 percent of cooperative members left during this period, which was compounded by the fact that in 1981 only 372 new cooperatives were formed as compared to the 1,663 newly formed cooperatives in 1980. Seeking to address these issues emerged a cooperative development strategy in the fall of 1982, which sought a slower, more steady expansion of the cooperative sector while simultaneously improving technical assistance, the provision of credit, and

⁷Two types of cooperatives predominated at this time. First, *cooperativas de crédito y servicio* (CCS) were composed of independent producers organized for the purpose of securing credit. Second, *cooperativas agrícolas Sandinistas* (CAS) were collectively owned and cultivated tracts of land. It is important to note here that smallholders with insufficient land frequently preferred receiving additional land as a private holding whereas landless workers were typically in favor of forming cooperatives (Fitzgerald 1985, 214).

producer prices. Despite being quite successful in consolidating cooperative production and improving the output of basic grains, new problems emerged: seasonal labor shortages in the agroexport sector and growing peasantry dissatisfaction with cooperative production (Deere and Marchetti 1985, 91-98; Martinez 1993, 478; Spoor 1995, 56-57).

In the context of the above issues and with the U.S. invasion of Grenada, an increase of Contra attacks, and fear of attempts to overthrow the Sandinista regime, October 1983 marked a submission to political considerations, an abandonment of gradualism in agrarian policy, and a third phase of reform. Accordingly, it was announced that 160,000 hectares of land would be transferred to the peasantry by the end of 1983 and 490,000 hectares over the course of 1984. In an attempt to consolidate their political base, the government permitted an accelerated titling of individual holdings, but by the end of 1984 only 8 percent of all land transferred to date had been to individuals (Luciak 1987, 120-121; Ryan 1995, 156-158; Spoor 1995, 58). Peasant discontent boiled over in June of 1985 and began threatening bourgeois property security when a group of landless peasants seized approximately 5,000 hectares of private land in the department of Masaya. Conceding to the peasants' demands the government reached compensation accords with the owners of the land and allowed the land to be transferred to the peasants in individual form, which signaled a relaxation of the promotion of cooperative development as well as a leaning to the peasantry in the clash of rural classes. From the beginning of agrarian reform through 1985, nearly all of land transferred to individuals was after the June seizures. Formalizing the concession to peasant demands and attempting to increase the pool of land for distribution, on January 11, 1986 the government decreed Law 14. This reform of the 1981 agrarian reform law (1) eliminated the lower limits on the expropriability of idle, underused, or rented land; (2) abolished compensatory measures for holders of idle land; and (3) allowed the government to declare the expropriation of any rural property under the right of public domain (Luciak 1987, 123-127; Martinez 1993, 481; Ryan 1995, 200-203).

By 1987 concessions to the demands of the peasantry were scaled back as the fulfillment of those demands (1) did not fit within the Sandinista's vision of cooperative development; (2) represented a sacrifice of modern, export-oriented agriculture to tradi-

tional forms of production; and (3) became politically unnecessary as Sandinistas came to believe that the contras were surviving more because of U.S. technological assistance than the support of the peasantry. Marking a fourth and final phase of agrarian reform policy, two major policy changes were made at this time. First, the 1987 economic plan urged that land transfers were only to occur if they were productivity enhancing, which, in accordance with Sandinista ideology, signaled preferential access to larger – although, not necessarily private – landholders. Further, emphasis was placed on moving landless peasants into previously deserted war zones and finding alternatives to land transfers for those classes. The preferred alternative was their absorption into already existing cooperatives (Ryan 1995, 203-204). Second, by 1989, expropriations for agrarian reform purposes were largely suspended and all ensuing reform was to be made on the basis of existing property relations (Martinez 1993, 481; Ryan 1995, 235-237). Thus, on the eve of the 1990 election, the Sandinistas were at a crossroads: due to Nicaragua’s continued economic deterioration the peasantry was increasingly demanding land, yet the Sandinistas, while not afraid to placate the peasantry with political rhetoric, were handcuffed by the ideological predisposition to promote cooperative development and the economic necessity of protecting agroexport production.

In reviewing the Sandinista years, Table 2.1 provides statistics on the evolution of the land distribution during this period. It is clear that, on the whole, the Sandinista revolution represented a loss to private, smallholder production as those producers owning less than 10 *manzanas* possessed roughly 2.1 percent of cultivable land before the revolution (1978), but only 1.6 percent of agricultural land in 1988. While medium-sized producers (those owning 10-200 *manzanas*) witnessed a small increase in their share of land after the Masaya seizures in 1985, overall their land shares decreased as well. Most notably, those producers owning 10-50 *manzanas* saw their shares decline from 15.4 percent before the revolution to 7.2 percent in 1988. While the state (APP) and cooperative sectors (both CCS and CAS) witnessed substantial land share increases throughout the 1980s, it is evident from the above discussion that these forms of production were insufficient to satiate peasant land hunger.

2.2.3 The Post-Sandinista Years, Structural Adjustment, and the Return of Daniel Ortega

Following the electoral loss of the Sandinistas in February of 1990, the government of Violeta Chamorro (1990-1996), under the guidance and funding of the World Bank and IMF Enhanced Structural Adjustment Facility (ESAF), implemented a structural adjustment program (SAP) in an attempt to correct the economic missteps of the Sandinista regime (Eberlin 2000, 47). Despite Nicaragua's unique history, the structural adjustment program implemented by the Chamorro government contained all of the features common to more orthodox programs: (1) the application of austerity measures; (2) trade liberalization; and (3) privatization. Accordingly, before turning to the current state of affairs, it is beneficial to briefly discuss the effect of each component of the structural adjustment program on smallholder production.

The application of austerity measures led primarily to a significant drop in credit and technical assistance for smallholders due to a general cutback of BANADES – the state development bank – operations, which was the principal source of credit for agricultural producers. For the 1995-1996 agricultural cycle, the acreage covered and total credit provided by BANADES was only 29 and 52 percent, respectively, of what it had been in 1991-1992. Moreover, the credit that was provided heavily prioritized export production and, therefore, larger landholders. Whereas small and medium-sized producers accounted for approximately 60 percent of production, their share of credit dropped from 56 percent in 1990 to 23 percent in 1993. Conversely, the share of credit provided to larger landholders grew from 31 to 71 percent from 1990 to 1992 (Jonakin 1997, 352-353; Stahler-Sholk 1997, 91). New collateral requirements, necessitating the presentation of formal title to one's property, exacerbated these trends, as smallholders frequently did not possess formal titles. Further, between 1989 and 1993 over 60 percent of BANADES offices were closed and in 1998 the operation closed its doors completely. As a result, smallholders increasingly lost access to other BANADES services, namely technical assistance, which was typically provided free of charge. As such, technical assistance reverted to being limited to larger producers who possessed the ability to pay (Enríquez 2010, 71-74).

With respect to trade liberalization, the average nominal tariff protection was reduced from 43 percent in January of 1990 to 19 percent in August of 1993. Specifically regarding the agricultural sector, it decreased from between 30 and 50 percent to between 21 and 31 percent throughout the same period (Eberlin 2000, 50). By 1999, the average nominal tariff was 10 percent for finished goods from outside the region and eliminated completely for intermediate and capital goods from the rest of Central America. The dramatic reduction in tariffs was further complemented by an overvalued currency, which converted the tariff levels for corns, beans, and sorghum into negative figures. Once again, as these are the crops traditionally produced by smallholders, the liberalization represented a major setback for those producers. In addition to falling output prices, smallholders were also at a relative disadvantage with respect to production costs. In the wake of currency devaluation and in an attempt to ensure that export production was not unduly harmed by more costly imported inputs, a new export promotion law (Decree 22-92 of March 1992) granted special import duty and sales tax exemptions to exporters, as well as income tax exemptions for non-traditional exporters. Domestically-oriented producers, and therefore smallholders, did not receive such support and thus saw rising production costs for most of the 1990s (Enríquez 2010, 75-80; Stahler-Sholk 1997, 94).

Given the radically altered political environment that accompanied structural adjustment, the privatization process had both direct and indirect effects. Regarding direct effects, with the passage of Decrees 10-90 and 11-90 in May of 1990 the Chamorro administration initiated the privatization of 351 state enterprises that were inherited from the Sandinistas, which accounted for 30 percent of GDP in 1990. While 44 percent of the state assets were simply returned to their pre-Sandinista owners, due to popular pressure, 25 percent of the privatized property was to be given to state workers, which, due to sectoral negotiations, resulted in workers being given 30 percent of the former state cattle properties, 33 percent in coffee, 32 percent in cotton, and a 25 percent share in the banana corporation (Stahler-Sholk 1997, 100–101). With respect to indirect effects, while under Laws 209 and 210 (enacted in November 1995) land cultivated cooperatively was to remain within that sector and under Law 278 (enacted in 1997) all land distributed by the Sandin-

ista agrarian reforms was legally recognized, former landowners continued to exert pressure to recover their land. As a result of legal maneuvers, force, as well as general economic insecurity, rapid decollectivization and concentration of land ensued. While national-level estimates suggest that approximately 32 percent of Sandinista agrarian reform land was sold between 1990 and 2000, certain departments witnessed more drastic changes. For example, in Masaya, an estimated 75 percent of land distributed to cooperatives in the 1980s had been sold to private producers by 2000 (Enríquez 2010, 82–84). Moreover, the vast majority (up to 83 percent in Rivas) of agrarian reform land marketed was sold to large-scale, wealthy landowners at well below market prices, which indicates pervasive “distress” sales (Jonakin 1996, 1187; Jonakin 1997, 354–355).

In summarizing the Chamorro years, the application of austerity measures, trade liberalization, and privatization, on the whole, negatively affected smallholder production via reduced access to credit and technical assistance, falling output prices and rising costs, and pressure from former landholders to recover their land. While structural adjustment did lead to moderate increases in foreign exchange earnings through agroexport, smallholders were largely excluded from this sector as they lacked resources (credit, technical assistance, etc.) to retool production. Referring again to Table 2.1, at first glance it appears that the cumulative effect of structural adjustment was not entirely unfavorable to smallholders as both the less than 10 and 10–50 *manzana* classes witnessed increases in their share of land from 1988 to 2001. However, according to Jonakin (1996):

These gains . . . were clearly artificial in the sense that they represented a shift of peasant-controlled or peasant-accessed lands out of the SAR sector [Sandinista agrarian reform beneficiary land]. Indeed, if in 1988 the small and medium-scale private sector together with the SAR sector comprised 79% of the farm area, then by 1993 those sectors had registered a net decrease of 6%. (1187–1188)

Thus, on closer inspection, while the dissolution of the state and collective sectors led to an expansion in all categories of privately held landholdings, the primary beneficiaries were large-scale producers and the peasantry and landless workers witnessed an overall diminished access to land throughout the 1990s.

With the end of the Chamorro presidency in 1996, Hurricane Mitch in 1998, and the Alemán and Bolaños governments largely characterized by corruption and infighting, change in the agricultural sector was quite limited in the late 1990s and early 2000s. However, given the ratification of the Dominican Republic-Central American Free Trade Agreement (DR-CAFTA) in 2005 and the reelection of FSLN leader Daniel Ortega to president in 2006, Nicaragua has seen some significant reforms made in the last few years. DR-CAFTA, a regional free trade agreement between five Central American countries (Costa Rica, El Salvador, Guatemala, Honduras, and Nicaragua), the Dominican Republic, and the United States, was signed on August 5, 2004 and went into effect for Nicaragua April 1, 2006 (Office of the United States Trade Representative 2010). In the wake of the Caribbean Basin Initiative (CBI)⁸ and the trade liberalization of the 1990s, the scope for DR-CAFTA trade barrier reductions was limited, though less so for agricultural commodities. For Nicaragua, corn (white and yellow), rice, beans, beef, pork, poultry, and dairy tariffs are to be reduced to zero over twenty years. While many of the reductions are gradual and some even have five (e.g. corn) or ten year (e.g. rice) grace periods, the long-term reductions are by no means trivial. For example, before the agreement the tariff on rice was 62 percent. In addition to tariff reductions on sensitive commodities, DR-CAFTA also established tariff-free quotas (TRQs), which permit tariff-free imports of certain commodities up to a quantitative limit, with increasing limits as time passes. While corn, rice, beans, beef, pork, poultry, and dairy are subject to these quotas, their effect on smallholders is perceived to be minimal (Morley 2006, 11-20). In a thorough study of the impact of DR-CAFTA on Nicaragua, Sánchez and Vos (2010)⁹ found modest output gains and poverty reduction as a result of the liberalization. However, the authors suggested that the gains of some sectors, namely (traditional) export agriculture (coffee and livestock) and meat processing have come at the expense of incomes and jobs among smallholders. Thus, as tariffs on crucial commodities are being slowly reduced and quotas are being lifted, it is reasonable to expect

⁸The CBI granted duty-free or lower than applicable preferential tariffs to a multitude of products imported into the United States from 24 countries in the Caribbean Basin. All DR-CAFTA countries were beneficiaries.

⁹See Bussolo and Niimi (2009) for an *ex-ante* assessment of the impact of DR-CAFTA on Nicaragua.

that smallholders will witness further losses in the future due to trade liberalization as the Ortega administration has expressed their commitment to DR-CAFTA (see, for example, GRUN [2009]).

Shortly after Daniel Ortega took office in January of 2007, the *Gobierno de Reconciliación y Unidad Nacional* (GRUN) released its economic growth and poverty reduction strategy, which is outlined in the National Human Development Plan (NHDP).¹⁰ Displaying a certain continuity with the preceding liberal regimes, the NHDP was structured in accordance with IMF guidelines and shows reverence for the international community, foreign investors, and the private sector. However, “the main premise behind this plan is that markets are imperfect and that to correct such imperfections the state must intervene through an appropriate regulatory framework. Further, the NHDP is based on the premise that the market can produce socially-undesirable outcomes in terms of inequality, the correction of which again requires state intervention” (5). Therefore, Sandinista interventionist elements clearly persist.

The GRUN productive strategy, like preceding regimes, is based on Nicaragua’s comparative advantage in agricultural production and “is geared toward stepping up food production, boosting the agro-industrial process, the rational exploitation of natural resources and investment in production” (23). Although, quite possibly for the first time in the history of Nicaragua, “poor decapitalized small farmers and small landowners are the active subjects of development. They are the pillar upon which the government’s planning and public management strategy toward rural areas is based” (24). Thus, food sovereignty is being promoted simultaneously with the development of agricultural exports. These ends are to be met with five primary strategies: (1) the regulation of land tenure by updating the physical cadastre and proceeding with delimitation, demarcation, titling, and physical planning; (2) developing rural infrastructure, namely by adding adequate irrigation systems; (3) promoting the association of small- and medium-sized producers in rural and coastal areas to accelerate capitalization and facilitate the transfer of technology; (4) en-

¹⁰The original NHDP has since been revised to reflect changing priorities in the wake of the international financial crisis. Discussed here is the most recent version.

surging smaller producers access to financial services; and (5) working to revolutionize agricultural technology used by small- and medium-sized food producers, primarily through expanded technical assistance. More specifically, four programs have been initiated with regard to these strategies: (1) the Productive Rural Development Sector Program; (2) the National Food Program; (3) the Rural Agro-Industry Program; and (4) the National Forestry Program (GRUN 2009, 24-25).

While the initiatives put forth by the Ortega government have yet to mature, some cursory conclusions can be drawn with regard to their success to date. With substantial support from the Bolivarian Alternative for Latin America (ALBA), in 2007 the government increased rural credit to small producers by 42 percent from the previous year. Further, in the first eighteen months of the *Hambre Cero* (Zero Hunger) program¹¹ nearly 18,500 families received partial or complete packages. Lastly, also in 2007, the provision of technical assistance nearly doubled, which was a trend that appeared to be continuing into 2008 (Enríquez 2010, 206-207). Overall, then, as smallholders have been historically neglected in the formulation of Nicaraguan agricultural policy, it appears that for the first time their needs have become a priority. Whether this priority shift will result in continued (and sustainable) growth and poverty reduction, however, remains to be seen, especially as gains made to date have relied considerably on funding from ALBA.

From the above historical narrative it is apparent that small-scale agricultural production in Nicaragua has displayed a certain resilience to adversity in both the economic and political realm. Structural adjustment, however, presented new challenges, namely by subjecting smallholders to international competition with little or no support throughout the liberalization period. Of further interest is the fact that structural adjustment provided a window of time in which policy “interference” appeared minimal and created a space for “voluntary” shifts in the distribution of agricultural landholdings. If, as Lipton (2010) suggested, the reduction of policy distortions would reveal the competitive advantage of small-scale producers, we would expect to see a tendency toward land fragmentation. How-

¹¹ *Hambre Cero* is a program that distributes a package of goods including a pregnant cow, a pregnant pig, a chicken and a rooster, feed for them, fruit and other trees, construction material for a stable, as well as training in a variety of areas.

ever, if the contentions of Collier (2008) as well as Collier and Dercon (2009) are correct, we would expect to see further land concentration. Accordingly, the post-Sandinista era presents a unique opportunity to analyze in a refined manner the viability of smallholder production in an integrated/globalized world. Thus, the following examines structural transformation in Nicaraguan agriculture from 1998 to 2005 by employing Markov chain analysis within an information-theoretic framework.

2.3 Methodology

In accordance with Zimmermann et al. (2009), structural transformation, as it pertains to agriculture, is defined as a large-scale change in the quantity of producers within certain predefined producer classifications (e.g. according to size, primary output, etc.). Padberg (1962) was among the first to suggest the modeling of structural change in agriculture as a Markov process and its use has since become pervasive. Three principal quantities are considered in a (first-order) Markov process: (1) a finite and mutually exclusive set of states of nature (e.g. discrete farm size categories); (2) the distribution of components (e.g. farms) in those states of nature; and (3) the transition probability matrix that shows the probabilities of moving among the states of nature. In what follows, so as to impose minimal distributional assumptions, we outline a semi-parametric, information-theoretic approach to the estimation of a first-order Markov model. Specifically, the estimation strategy employs Generalized Cross Entropy (GCE) in the recovery of the aforementioned transition probability matrix.

Following Golan (2008), the stationary first-order model can be formulated as follows:

$$\sum_{i=1}^N y_{itj} = \sum_{i=1}^N \sum_{k=1}^K p_{kj} y_{i,t-1,k} \quad (2.1)$$

where for farm $i = 1, 2, \dots, N$ in period $t = 1, 2, \dots, T$ the indices j and k represent the states in periods t and $t - 1$, respectively. Further, y_{itj} is a K -dimensional vector of binary variables for each farm that takes the value $y_{itj} = 1$ if state j is observed and $y_{itj} = 0$ for the other $K - 1$ states. Lastly, p_{kj} are elements of the transition probability matrix

(TPM) P , which is an unknown and unobservable $K \times K$ matrix where $\sum_{j=1}^K p_{kj} = 1$. The above, then, can be generalized to T periods. To account for noise in the observed data, however, the generalization is accompanied by the specification of the moment condition as a stochastic condition as follows:

$$\sum_{t=2}^T \sum_{i=1}^N y_{itj} = \sum_{t=1}^{T-1} \sum_{i=1}^N \sum_{k=1}^K p_{kj} y_{itk} + \sum_{t=1}^{T-1} \sum_{i=1}^N \varepsilon_{itj} \quad (2.2)$$

or

$$\sum_{t=2}^T \sum_{i=1}^N y_{itj} = \sum_{t=1}^{T-1} \sum_{i=1}^N \sum_{k=1}^K p_{kj} y_{itk} + \sum_{t=1}^{T-1} \sum_{i=1}^N \sum_{m=1}^M w_{itjm} v_{jm} \quad (2.3)$$

where the additive noise $\varepsilon \in [-1, 1]$ has a zero mean, v is an $M \geq 2$ dimensional support vector for the j^{th} state, and W is the set of probability distributions defined on the support such that their expected value is ε_{itj} (i.e. $\sum_m w_{itjm} v_{jm} = \varepsilon_{itj}$ and $\sum_m w_{itjm} = 1$).

The above specification operates under the assumption that the transition probability matrix is stationary or independent of observed micro- and macro-level covariates. Theoretically, strategic policy or environmental variables, including producer-specific characteristics, may influence the process of structural transformation thereby rendering the stationarity assumption particularly stringent. Thus, in an attempt to relax this assumption, we model p_{kj} as a function of explanatory variables z_{its} where $s = 1, 2, \dots, S$ denotes the explanatory variable for the i^{th} farm at time t . As the functional form for this relationship is unknown to the researcher, it is conventionally captured via the cross moments:

$$\sum_{t=2}^T \sum_{i=1}^N y_{itj} z_{its} = \sum_{t=1}^{T-1} \sum_{i=1}^N \sum_{k=1}^K p_{kj} y_{itk} z_{its} + \sum_{t=1}^{T-1} \sum_{i=1}^N \sum_{m=1}^M z_{its} w_{itjm} v_{jm}, \quad (2.4)$$

which then gives a system of KS equations (i.e. an equation for each Markov state with respect to each explanatory variable).

The goal, then, is to recover P and W . However, given the proposed model, this is a classic case of an ill-posed problem as the number of unknown quantities exceeds the number of known quantities. Faced with an under-determined problem, traditional estimation techniques fail or require very strong restrictions and/or assumptions. “The

researcher wishes to extract the available information from the data, but wants to do it with minimal *a priori* assumptions. . . . Which one of the infinitely many solutions should one choose? . . . [T]he one solution chosen is based on an information criterion that is related to Shannon’s information measure – entropy” (Golan 2008, 5).

To understand Maximum Entropy (ME) formalism in the simplest terms consider recovering P within a pure inverse framework (i.e. Eq. [2.1]). Jaynes (1957a,b) proposed a constrained optimization problem that involves maximizing the Shannon (1948) entropy (or uncertainty) measure

$$H(\mathbf{p}) = - \sum_{k=1}^K \sum_{j=1}^K p_{kj} \ln p_{kj} \quad (2.5)$$

subject to the appropriate moment consistency and proper probability constraints where $H(\mathbf{p})$ reaches a maximum when $p_{k1} = p_{k2} = \dots = p_{kK} = 1/K \ \forall k$ and $p_{kj} \ln p_{kj} = 0$ for $p_{kj} \rightarrow 0$. The resulting solution is “the one that could have been generated in the greatest number of ways consistent with what we know” (Golan et al. 1996, 21). Intuitively, among those values of P that satisfy the specified constraints, the resulting solution is that which is most uniformly distributed (i.e. the most conservative estimates). Thus, ME formalism, on a basic level, amounts to defining an objective function or criterion through which to select among infinitely many solutions in an under-determined problem.

The above framework is readily generalized to incorporate noise as well as prior information. First, consider the inclusion of noise in the model (i.e. Eq. [2.3]), which is an application of Generalized Maximum Entropy (GME). The objective function is as follows:

$$H(\mathbf{p}, \mathbf{w}) = - \sum_{k=1}^K \sum_{j=1}^K p_{kj} \ln p_{kj} - \sum_{i=1}^N \sum_{t=1}^{T-1} \sum_{j=1}^K \sum_{m=1}^M w_{itjm} \ln w_{itjm} \quad (2.6)$$

where P and W remain as defined above and the intuition regarding the solution is identical to the pure inverse problem. Perhaps more interestingly, as a second step we can introduce prior information on P and W as follows:

$$D(\mathbf{p}, \mathbf{w} \parallel \mathbf{p}^0, \mathbf{w}^0) = \sum_{k=1}^K \sum_{j=1}^K p_{kj} \ln \left(\frac{p_{kj}}{p_{kj}^0} \right) + \sum_{i=1}^N \sum_{t=1}^{T-1} \sum_{j=1}^K \sum_{m=1}^M w_{itjm} \ln \left(\frac{w_{itjm}}{w_{itjm}^0} \right) \quad (2.7)$$

where the definitions of P and W again remain unchanged, but this time p_{kj}^0 and w_{itjm}^0 represent elements of matrices of prior information on P and W . Termed Generalized Cross Entropy (GCE), now the values of P and W that minimize $D(\mathbf{p}, \mathbf{w} \parallel \mathbf{p}^0, \mathbf{w}^0)$ are those that are “closest” to the researcher’s chosen priors subject to the moment consistency and proper probability constraints. Further, it can be shown that GCE is a generalization of GME formalism, as with uniform priors the GCE solution is identical to that of GME (see Golan et al. [1996] or Golan [2008] for a thorough discussion).

Given the definition of the GCE objective function as well as the relevant moment constraints, the Lagrangian can be formulated as follows:

$$\begin{aligned} \mathcal{L} = & \sum_{k=1}^K \sum_{j=1}^K p_{kj} \ln \left(\frac{p_{kj}}{p_{kj}^0} \right) + \sum_{i=1}^N \sum_{t=1}^{T-1} \sum_{j=1}^K \sum_{m=1}^M w_{itjm} \ln \left(\frac{w_{itjm}}{w_{itjm}^0} \right) \\ & + \sum_{s=1}^S \sum_{j=1}^K \lambda_{sj} \left[\sum_{t=2}^T \sum_{i=1}^N y_{itj} z_{its} - \sum_{t=1}^{T-1} \sum_{i=1}^N \sum_{k=1}^K p_{kj} y_{itk} z_{its} - \sum_{t=1}^{T-1} \sum_{i=1}^N \sum_{m=1}^M z_{its} w_{itjm} v_{jm} \right] \\ & + \sum_{k=1}^K \mu_k \left[1 - \sum_{j=1}^K p_{kj} \right] + \sum_{i=1}^N \sum_{t=1}^{T-1} \sum_{j=1}^K \rho_{itj} \left[1 - \sum_{m=1}^M w_{itjm} \right], \end{aligned} \quad (2.8)$$

which then yields the following solutions:

$$\hat{p}_{kj} = \frac{p_{kj}^0 \exp \left(\sum_{t=1}^T \sum_{i,s} y_{itk} z_{its} \hat{\lambda}_{sj} \right)}{\sum_j p_{kj}^0 \exp \left(\sum_{t=1}^T \sum_{i,s} y_{itk} z_{its} \hat{\lambda}_{sj} \right)} \equiv \frac{p_{kj}^0 \exp \left(\sum_{t=1}^T \sum_{i,s} y_{itk} z_{its} \hat{\lambda}_{sj} \right)}{\Omega_k(\hat{\lambda})} \quad (2.9)$$

and

$$\hat{w}_{itjm} = \frac{w_{itjm}^0 \exp \left(\sum_s z_{its} v_{jm} \hat{\lambda}_{sj} \right)}{\sum_m w_{itjm}^0 \exp \left(\sum_s z_{its} v_{jm} \hat{\lambda}_{sj} \right)} \equiv \frac{w_{itjm}^0 \exp \left(\sum_s z_{its} v_{jm} \hat{\lambda}_{sj} \right)}{\Psi_{itj}(\hat{\lambda})} \quad (2.10)$$

where $\Omega_k(\hat{\lambda})$ and $\Psi_{itj}(\hat{\lambda})$ are normalization factors known as partition functions. Notice here that there are no closed-form solutions as $\hat{\lambda}_{sj}$ is unknown. While numerical optimization of the constrained (primal) model is indeed a possibility, it is typically considered computationally superior to construct an unconstrained dual model, which is essentially equivalent to a concentrated likelihood function. To derive the dual formulation, we start

with the Lagrangian and then insert the GCE solutions, which already satisfy the proper probability requirements so these constraints can be dropped. Upon simplification, we have:

$$\ell(\boldsymbol{\lambda}) = \sum_{t=2}^T \sum_{j=1}^K \sum_{i,s} y_{itj} z_{its} \lambda_{sj} - \sum_k \ln \Omega_k(\boldsymbol{\lambda}) - \sum_{i,t,j} \ln \Psi_{itj}(\boldsymbol{\lambda}), \quad (2.11)$$

which can be optimized numerically and the resulting values for $\hat{\lambda}_{sj}$ can then be substituted into Eqs. (2.9) and (2.10) (see Golan et al. [1996] or Golan [2008] for the derivations).

With the posterior probability distributions in hand, we can (1) investigate the quantity of information embodied in the system and (2) calculate “state” elasticities for each of the covariates. With respect to the examination of the informational content of the TPM, the normalized entropy measure is provided:

$$S(\hat{\mathbf{p}}) = \frac{-\sum_k \sum_j \hat{p}_{kj} \ln \hat{p}_{kj}}{-\sum_k \sum_j \hat{p}_{kj}^0 \ln \hat{p}_{kj}^0} \quad (2.12)$$

and

$$S(\hat{\mathbf{p}}_k) = \frac{-\sum_j \hat{p}_{kj} \ln \hat{p}_{kj}}{-\sum_j \hat{p}_{kj}^0 \ln \hat{p}_{kj}^0} \quad (2.13)$$

where Eq. (2.12) is the normalized entropy measure for the entire TPM and Eq. (2.13) is the measure of information embodied in each row. A normalized entropy value of one represents a situation where the information embodied in the posterior probabilities is identical to that of the prior distribution and, as such, the data has not conveyed any additional information. As the measure decreases toward zero, the data has “pulled” the posterior probabilities in a direction of less uncertainty/uniformity than that of the prior distribution (Golan and Vogel 2000). Further, the Entropy Ratio (ER) test is used to conduct a formal hypothesis test of the information embodied in the *entire* system:

$$ER = 2H_U - 2H_R = 2H(\mathbf{p}^0, \mathbf{w}^0) - 2H(\mathbf{p}, \mathbf{w}) \quad (2.14)$$

where H_U is the unrestricted hypothesis, H_R is the restricted hypothesis, and $H(\cdot)$ is defined above. The Entropy Ratio statistic converges in distribution to χ_{SK-1}^2 (see Golan and Vogel

[2000] or Golan [2008] for discussion and derivation). Finally, to investigate the effect of each of the covariates on the number of farms in each Markov state, following Karantininis (2002) as well as Tonini and Jongeneel (2009), the following elasticity is calculated:

$$E_{js}^y = \left(\sum_{k=1}^K \frac{\partial \hat{p}_{kj}}{\partial \bar{z}_s} \cdot \bar{y}_k \right) \frac{\bar{z}_s}{\bar{y}_j} = \frac{\partial \bar{y}_j}{\partial \bar{z}_s} \frac{\bar{z}_s}{\bar{y}_j} = \frac{\bar{z}_s}{\bar{y}_j} \left[N(T-1) \sum_{k=1}^K \hat{p}_{kj} \bar{y}_k^2 \left(\hat{\lambda}_{sj} - \sum_{j=1}^K \hat{p}_{kj} \hat{\lambda}_{sj} \right) \right] \quad (2.15)$$

where bar notation denotes sample means. Now, given a thorough discussion of the methodological framework it is possible to elaborate upon the data required for the analysis.

2.4 Data

In accordance with the methodological framework, there are three basic data requirements for the analysis: (1) producer-specific information on state membership at different points of time; (2) data on the relevant policy/environmental variables at those points in time; and (3) information on priors and support vectors. Nearly all of the data requirements are adequately fulfilled by Nicaragua's *Encuesta Nacional de Hogares Sobre Medición de Nivel de Vida* (EMNV). The EMNV is a nationally-representative living standards measurement survey that contains detailed information regarding household characteristics, individual-level demographic traits, household expenditure and income information, as well as considerable data on agricultural and livestock production. The survey is panel in nature and consists of 4,209, 4,191, and 6,879 observations (i.e. households) for the years 1998, 2001, and 2005, respectively. All data, unless otherwise noted, were compiled and disseminated by the Food and Agriculture Organization of the United Nations' Rural Income Generating Activities project (RIGA 2011).

The 1998 survey, based on the population census of 1995, sampled the population by (1) random selection of census segments (50-60 households per segment) with probabilities of selection proportionate to population size and (2) random selection of a fixed number of households in each segment (12 in urban segments and 10 in rural segments). The 2001 sample included all households surveyed in 1998 that remained within their respective segment, any households that did not respond to the 1998 survey, as well as a number

of new households, which were selected in proportion to population growth. The 2005 survey took a similar approach, but selection of new households was based on the 2005 population census. Importantly, given the need to track individual producers across all time periods, any households that were not surveyed in all years were necessarily dropped from the sample. Further, as some households did not report operating land for agricultural or livestock purposes in any of the survey years, these households were excluded as well. The resulting balanced sub-panel contains 1,208 observations in each of the three years.

Complete definitions and descriptive statistics of all variables utilized are provided in Tables 2.2 and 2.3, respectively. All variables reported in value terms are normalized by a producer price index¹² (base year 1998) derived from data available through the Food and Agriculture Organization’s FAOSTAT (FAO 2011a). Regarding the first data requirement, the primary concern in the analysis of structural transformation in agricultural and livestock production is the allocation or reallocation of land across different sizes of producers. However, the analysis need not be confined to structural transformation in the size of landholdings as land use is yet another dimension of concern. Deininger et al. (2003) developed a two-dimensional typology of rural Nicaraguan producers based on the size of a given household’s landholdings (i.e. small or large)¹³ and the use to which those households put that land (i.e. maize or bean, livestock, coffee, or diversified production), where use was ascertained from income data. The state definitions used here are essentially a refinement of the two-dimensional approach employed by Deininger et al. (2003).

With respect to the size-oriented state definitions, the analysis is conducted with two alternative categorizations of operational landholdings. Regarding the first alternative, the size-oriented states are based on producer size classes as reported in Nicaragua’s 2001 agri-

¹²The commodities included in the index are those with price and quantity data available in each year in question. The list of goods is as follows: bananas, beans, cabbages, cassava, cattle meat, chicken meat, cocoa beans, coffee, cow milk, fresh fruit, goat meat, groundnuts, hen eggs, horse meat, maize, pig meat, pineapples, plantains, potatoes, rice, seed cotton, sesame seed, sheep meat, sorghum, soybeans, tobacco, and tomatoes. The index is a Fisher index, which is calculated as the geometric mean of the Laspeyres and Paasche indexes (see Coelli et al. [2005] for the specific calculation).

¹³The cutoff between small and large farms was 20 *manzanas* for livestock producers and 5 *manzanas* for the other categories.

Table 2.2: Variable Definitions

Variable	Definition
Land Owned	Quantity of cultivable land, pastureland, or forestland owned (<i>manzanas</i>)
Land Operated	Land owned plus land rented, borrowed, or sharecropped <i>from</i> others less land rented, borrowed, or sharecropped <i>to</i> others (<i>manzanas</i>)
Value of Output	The value of output is the sum of revenue from agricultural and livestock production. Agricultural revenue includes the sale of crops and crop by-products, the value of own crop consumption as well as sales and the value of own consumption from forestry production. Livestock revenue includes the sale of livestock and livestock by-products as well as the value of own livestock consumption (<i>córdoba</i>).
Output Share (Beans and Maize)	The value of output derived from beans and maize production divided by the total value of output
Output Share (Livestock)	The value of output derived from livestock production divided by the total value of output
Land Productivity	The value of output divided by the quantity land operated
Labor Productivity	The value of output divided by the reported days of household and hired labor utilized
Agricultural Wage	The median daily wage paid to hired labor. The median agricultural wage of the smallest possible administrative division (i.e. municipality, department, etc.) is attributed to those producers that did not hire labor (<i>córdoba</i>).
Land Price	Per <i>manzana</i> purchase price of land. The median purchase price of the smallest possible administrative division (i.e. municipality, department, etc.) is attributed to those producers that did not report owning land (<i>córdoba</i>).
Price of Beans	Per pound unit value of beans sold. The median price of beans of the smallest possible administrative division (i.e. municipality, department, etc.) is attributed to those producers that did not sell beans (<i>córdoba</i>).

Continued on Next Page ...

Table 2.2 – Continued

Variable	Definition
Price of Cattle	Per head unit value of cattle sold. The median price of beef of the smallest possible administrative division (i.e. municipality, department, etc.) is attributed to those producers that did not engage in livestock production (<i>córdoba</i>).
Price of Coffee	Per pound unit value of coffee sold. The median price of coffee of the smallest possible administrative division (i.e. municipality, department, etc.) is attributed to those producers that did not sell coffee (<i>córdoba</i>).
Price of Maize	Per pound unit value of maize sold. The median price of maize of the smallest possible administrative division (i.e. municipality, department, etc.) is attributed to those producers that did not sell maize (<i>córdoba</i>).
Price of Rice	Per pound unit value of rice sold. The median price of rice of the smallest possible administrative division (i.e. municipality, department, etc.) is attributed to those producers that did not sell rice (<i>córdoba</i>).
Credit	A binary variable that takes on the value of one if a given producer reported receiving credit for either production or consumption purposes
Title	A binary variable that takes on the value of one if a given producer reported holding a title to any owned landholdings
Technical Assistance	A binary variable that takes on the value of one if a given producer reported receiving technical assistance
Age of HH Head	Age of the household head
Education of HH Head	Years of education of the household head

cultural census results (INEC, MAG-FOR, FAO, and UE 2001). However, to ensure that each state is sufficiently populated in each year, it has proven necessary to aggregate/-combine select classes. Denoting this definitional approach AC, the first column of Table 2.4 reports the resulting states (in *manzanas*) under the corresponding label. As for the

Table 2.3: Descriptive Statistics

Variable	1998		2001		2005	
	Mean	SD	Mean	SD	Mean	SD
Land Owned	11.54	31.27	11.19	27.34	12.17	31.29
Land Operated	12.44	31.06	11.93	27.07	12.60	30.81
Value of Output	5,878.77	7,780.83	9,230.98	13,959.62	8,689.59	12,197.40
Output Share (Beans and Maize)	0.32	0.35	0.28	0.31	0.45	0.39
Output Share (Livestock)	0.29	0.33	0.36	0.34	0.27	0.33
Land Productivity	1,202.07	1,749.88	1,974.47	4,791.72	1,652.16	1,923.40
Labor Productivity	17.73	26.72	24.95	36.08	13.51	16.99
Agricultural Wage	16.60	6.01	22.55	5.52	21.84	4.90
Land Price	2,409.17	2,333.98	3,445.96	3,904.85	4,602.31	4,830.04
Price of Beans	2.90	0.71	2.37	0.61	2.82	0.50
Price of Cattle	1,952.88	830.34	2,532.60	945.51	2,914.22	819.03
Price of Coffee	8.61	5.21	3.01	2.39	4.28	1.29
Price of Maize	0.90	0.81	0.90	0.27	1.07	0.28
Price of Rice	1.46	0.33	1.65	0.41	1.97	0.42
Credit	0.12	0.32	0.28	0.45	0.26	0.44
Title	0.38	0.48	0.42	0.49	0.43	0.50
Technical Assistance	0.13	0.33	0.11	0.31	0.05	0.22
Age of HH Head	46.96	15.29	49.40	15.50	49.60	15.80
Education of HH Head	2.45	3.15	2.51	3.25	3.41	4.04
N	1,208		1,208		1,208	

Note: To avoid numerical overflow, the data used in the analysis is necessarily scaled. As scaling does not affect the results in any way, here the unscaled data is presented.

second alternative, we undertake a refinement of the AC states such that they correspond with observed breaks in the data. The purpose of this refinement is to minimize the sensitivity of the results to small changes in the definitions. Figure 2.1 presents a histogram of operational landholdings as a justification for this definitional approach. Denoting this data-driven definition as DD, Table 2.4 once again reports the resulting states (in *manzanas*) under the corresponding label.

Moving to the use-oriented states, Nicaraguan agricultural and livestock producers can be combined into four mutually exclusive groups: beans and maize producers, livestock ranchers, coffee growers, and diversified farmers (Deininger et al. 2003). However, insufficient observations on coffee growers necessitates grouping these producers with the diversified farmers. Accordingly, a given producer is deemed a member to one of the re-

Table 2.4: Markov States (Aggregate Proportions)

		1998		2001		2005	
State		AC	DD	AC	DD	AC	DD
Entry/Exit		24.09	24.09	21.94	21.94	20.61	20.61
AC: <2.5 DD: <2.75	BM	13.66	13.74	11.09	11.09	22.02	22.10
	L	6.13	6.13	9.52	9.52	3.06	3.06
	D	11.84	11.84	10.02	10.02	7.45	7.45
AC: 2.5-5 DD: 2.75-6.75	BM	6.46	7.37	5.30	6.04	9.11	10.60
	L	1.90	2.32	4.47	6.04	2.24	2.73
	D	6.54	7.78	6.46	7.53	4.22	4.97
AC: 5-20 DD: 6.75-18.5	BM	5.63	4.22	3.81	2.81	7.86	5.55
	L	2.32	1.82	6.87	4.47	4.30	3.39
	D	7.78	5.46	6.21	4.55	4.39	2.90
AC: 20-50 DD: 18.5-55	BM	2.48	2.90	1.99	2.40	3.06	3.89
	L	2.24	2.48	3.81	4.72	4.22	4.97
	D	2.81	3.97	2.48	3.23	1.24	1.99
AC: >50 DD: >55	BM	1.08	1.08	0.99	0.83	1.24	1.16
	L	2.57	2.40	3.15	3.06	4.06	3.73
	D	2.48	2.40	1.90	1.74	0.91	0.91
Total		100	100	100	100	100	100

maining three categories if more than 50 percent of their agricultural and/or livestock revenue is derived from the corresponding source. Figures 2.2 and 2.3 present histograms for the relevant output share variables as a justification for the cutoff employed. Further, we denote beans and maize, livestock, and diversified producers as BM, L, and D, respectively. Finally, and importantly, an entry/exit category is included for those producers that did not engage in agricultural or livestock production in all of the surveyed years.

With a five-fold size-oriented classification for both the AC and DD definitions, three use-oriented states, and an entry/exit category, we have a total of sixteen possible states. So as to get a better understanding of the data as well as the states utilized, Table 2.4 presents the proportion of producers falling into each of the sixteen states for each of the survey years. The proportions are presented once for classifications based on the AC definition and once for classifications based on the DD definition. In general, it should be noted that the alternative size definitions result in aggregate proportions that are quite similar

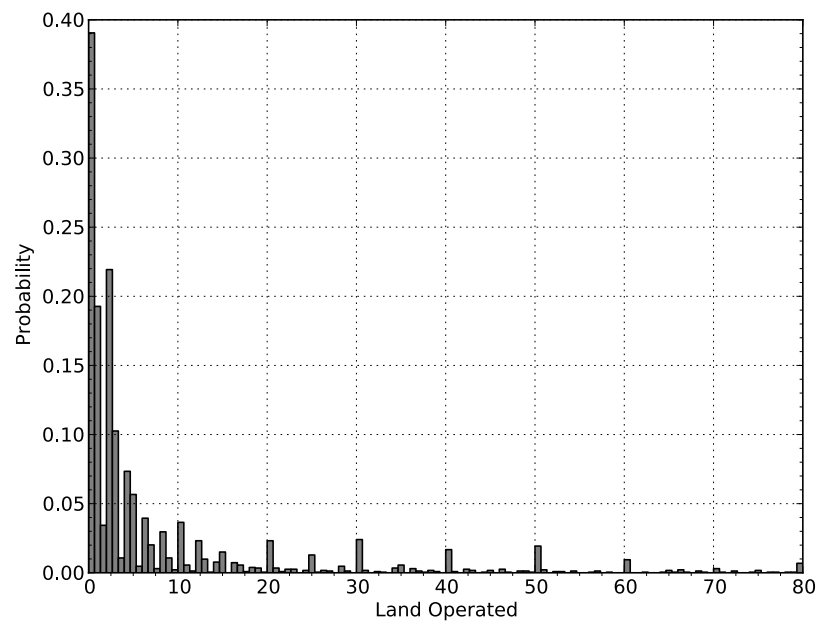


Figure 2.1: Histogram (Land Operated)

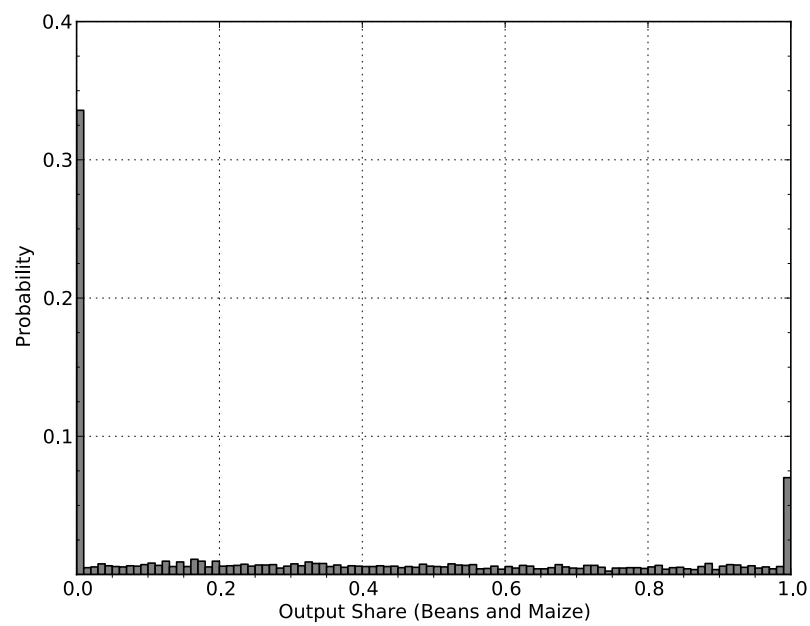


Figure 2.2: Output Share (Beans and Maize)

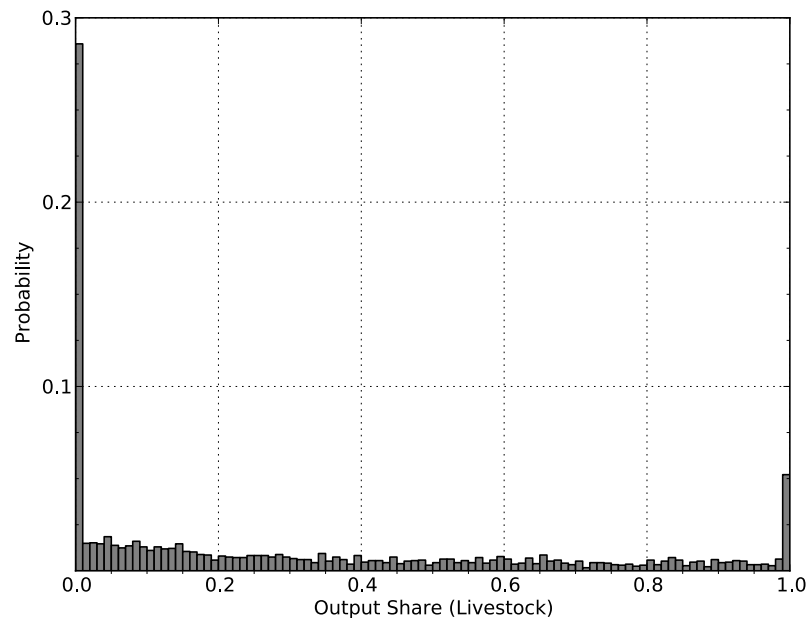


Figure 2.3: Output Share (Livestock)

and sometimes identical, which simply affirms that the DD definitions are by no means a radical departure from the AC definitions. Regarding specific trends, it is evident from the continual decline in the proportion of producers in the entry/exit category that there existed a net entry of farms over the sample period. Determination of the point of entry, although, requires further analysis. Concerning changes in the land distribution, even though Table 2.3 shows no definitive trends in the mean size of operational landholdings, it would be misleading to conclude that no distributional changes occurred. If one aggregates over the use-oriented classes in Table 2.4, it can be seen that from 1998-2001 the smallest and largest size classes, independent of the definition used, witnessed non-negligible decreases in their shares whereas the three medium-sized classes exhibited increases. Interestingly, nearly the exact opposite trend was observed from 2001-2005. While the smallest and two largest size classes saw increasing shares in this period, the medium-sized classes witnessed net decreases. Such a bifurcation of the land distribution, as will be seen, displays a propensity to persist and emerges as a characteristic of structural change in Nicaragua that deserves

careful consideration. It should, however, be noted that each size class exhibited a net increase from 1998-2005,¹⁴ which can be attributed to the shrinking entry/exit category.

Like the summary statistics for mean operational landholdings, there does not appear to be any discernible trends in the share of output variables in Table 2.3.¹⁵ Again, however, by no means does this indicate that no changes occurred. Aggregating across the size-oriented classes in Table 2.4, a certain specialization is evident as from 1998-2005 both the beans and maize as well as livestock classes witnessed increases in their shares, whereas the diversified category saw a substantial decline. While the trend holds for the diversified producers for 1998-2001 as well 2001-2005, this is not the case for the other two categories. The beans and maize states saw decreases from 1998-2001, but this was offset by a large increase in their shares from 2001-2005. Conversely, whereas livestock producers exhibited significant increases from 1998-2001, this was partially diminished from 2001-2005. Overall, while some interesting trends emerge from Table 2.4, it is clear that a more robust understanding of structural change in Nicaragua's agricultural and livestock sector, especially as it pertains to the fate of small-scale production, requires a more refined approach.

As for the second data requirement, in a comprehensive review of the literature on the subject, Zimmermann et al. (2009) discussed the primary determinants of structural transformation. The following lists the relevant determinants and briefly discusses their theoretical importance as well as the variables employed in the analysis (see Table 2.2 for variable definitions):

- (1) *Technology*: Discussion of the impact of technological change on structural transformation typically refers to Cochrane's treadmill (Cochrane 1958) whereby first adopters of a new technology witness a reduction in (expected) per unit costs, which results in temporary benefits until the innovation spreads and the prices of farm commodities

¹⁴The only exception to this statement is that, when using the DD state definitions, the largest size class witnessed a net decrease from 1998-2005.

¹⁵Note that the category for diversified producers is simply a residual category. As such, summary statistics for the relevant output share variable are not provided.

fall. The resulting revenue reduction forces other farmers to adopt the new technology or exit the sector, thereby leaving resources to be acquired by the innovating producers (Harrington and Reinsel 1995). To distinguish between labor-saving (i.e. mechanization) and land-saving (i.e. biochemical) advances, producer-specific land productivity and labor productivity variables are employed to capture the influence of technological change on structural transformation.

(2) *Input and Output Prices*: According to Structure-Conduct-Performance theory of industrial organization, performance (i.e. profits, prices, and innovation) is a function of structure (i.e. buyer and seller concentration, conditions of entry and exit, and vertical integration) and conduct (i.e. product differentiation and pricing policies), whereas conduct is a function of structure, and structure is a function of conduct (Boehlje 1992). As such, output and input prices play an especially important role in the process of structural transformation. Thus, the prices of the primary commodities produced in Nicaragua's agricultural and livestock sector (i.e. beans, cattle, coffee, maize, and rice), as well as the prices of the primary inputs utilized (i.e. land and labor), are included in the model. Of these variables the price of labor or the prevailing wage deserves special mention. Whereas for the large-scale capitalist producer the wage rate plays a role largely analogous to any other input price, for the semi-proletarian small-scale producer the issue is more complex. On the one hand, as the opportunity cost of engaging in own agricultural or livestock production increases due to increases in off-farm wages, farmers will tend to leave the sector until wages equalize. On the other hand, increases in income from off-farm activities can be used for short-run subsidization of agricultural operations, which may facilitate the continuation of cultivation (Harrington and Reinsel 1995). Therefore, the effect of the prevailing wage on smallholders is an empirical matter.¹⁶

¹⁶The effect of the wage rate on structural transformation is captured via the inclusion of the agricultural wage rate in the model. While an argument could be made that a (more general) rural wage rate is the appropriate wage rate to use here, the high degree of correlation between the two rates renders the distinction inconsequential. Moreover, the data on agricultural wages appears to be the more precise/reliable source.

(3) *Policy*: The institutional and legal environment in addition to specific public programs affect structural change in a multitude of ways. In a developing country context, access to credit, holding the title to one's plot, or the receipt of technical assistance are all central in determining a given producer's ability to undertake new investments, participate in the land market, and/or successfully implement technological innovations. Each of these three phenomena are included to account for the effect of policy on structural change.

(4) *Demographics*: Discussions of demographic considerations typically refer to the "life cycle hypothesis" where "structural change . . . is the result of changing patterns of entry, growth, and exit that occur over the lifetimes of farmers. Different age cohorts experience highly similar patterns that are marginally affected by changes in economic conditions, government programs, or external shocks" (Harrington and Reinsel 1995, 7). The impact of the age structure of farm operators on structural transformation is captured through the inclusion of the age of the household head.

(5) *Human capital*: Differences in managerial capability and/or education levels influence structural change through the differential capacity of firm managers to acquire and process information, which can be used to allocate the firm's resources more efficiently and facilitate the evaluation of new technologies (Boehlje 1992). Years of education of the household head is used here to account for such differences in human capital.

Looking once again to Table 2.3, three interesting trends in the above policy/environmental variables are worth noting. First, with respect to land and labor productivity, we see a peak in both means in 2001. As regression in land and labor productivity is unlikely, it would appear that these variables are capturing some underlying output volatility, which is most plausibly weather induced. However, as investment decisions are not made independently of risk considerations (see, for example, Rosenzweig and Binswanger [1993]), the above discussion of Cochrane's treadmill holds, but with the added caveat that producers may derive temporary benefits from adopting technologies that are resilient to adverse weather conditions. Second, looking to input prices, while there are no significant trends in the agri-

cultural wage, it is clear that the price of land trends definitively upward, which reflects increasing demand and is consistent with the above-discussed net entry into the sector. Third, regarding the policy variables, it is evident that, in all years, a relatively low proportion of producers obtained credit, possessed a title, and/or received technical assistance. While the credit and title variables exhibit some increases from 1998-2005, the proportion of producers receiving technical assistance declined by over 50 percent. As smallholders most often bear the burden of such policy issues (Jonakin 1997), the descriptive statistics highlight the important role these variables play in shaping structural change. As a final note, while the aforementioned covariates theoretically capture the desired phenomena, we did explore the inclusion of a number of potentially relevant country-level variables (e.g. inflation, interest, and unemployment rates). However, the limited number of cross-sections posed identification issues, which precluded their incorporation.

With respect to the third data requirement, a brief discussion of the priors and support vectors used in the analysis is necessary. Regarding prior information on P , a similar strategy to Karantininis (2002) is adopted. To construct the $K \times K$ matrix of priors, begin with a matrix of uniform probabilities (i.e. $p_{kj}^0 = 1/K$) and set to zero (1) those elements that correspond to an expansion or contraction of more than three *size* categories and (2) any unidentified elements (i.e. elements corresponding to transitions observed with zero frequency). Then, allocate the remaining $1 - \sum_j p_{kj}$ in a uniform manner across the non-zero elements. In essence, for the identified elements, the resulting matrix of priors reflects the belief that (1) farms do not grow/contract more than three size categories in a given transition and (2) there are no implausible states to (from) which a farm can enter (exit). As prior information regarding the remaining probability distribution is highly uncertain, so as to proceed conservatively, these elements remain uniformly distributed.

Regarding prior information on W , the disturbance ε_{itj} is assumed to be uniformly and symmetrically distributed around zero as there is no *a priori* justification for assuming otherwise. Concretely, for $M = 3$, $w_{itjm}^0 = 1/M = 1/3$. With respect to support vectors, following Golan et al. (2007), given that each Markov state is reasonably characterized

by a different variance in the error term, the specification of a common support can lead to relatively large bounds for some classes with the consequence being that the estimated transition probabilities are likely to converge to the priors and underutilize the available information in the data. In order to avoid this, the support bounds are uniquely defined for each Markov state by associating the data on y_j with a Poisson process where the level of noise for each state corresponds to the expected number of producers in that state. Relying on the “three sigma” rule of Pukelsheim (1994) and recalling that the errors are naturally confined to the interval $[-1, 1]$, the resulting standard deviation of y_j is multiplied by three and normalized so as to confine the supports to the desired interval. The support vector, then, is defined as follows:

$$\mathbf{v}_j = (-c_j, 0, c_j) = \left[\frac{-3\sqrt{\sum_{it} y_{itj}}}{\max_j (3\sqrt{\sum_{it} y_{itj}})}, 0, \frac{+3\sqrt{\sum_{it} y_{itj}}}{\max_j (3\sqrt{\sum_{it} y_{itj}})} \right]. \quad (2.16)$$

With the definition of the Markov states, the policy/environmental variables, as well as the prior information and support vectors utilized, it is now possible to examine the results of the GCE estimation.

2.5 Results

Tables 2.5-2.9 report the results of the GCE estimation. Regarding the TPMs, we have a normalized entropy measure of 0.63 for both Tables 2.5 and 2.6 as well as Entropy Ratio statistics of 636.14 (p -value < 0.01) and 636.23 (p -value < 0.01) for Table 2.5 and 2.6, respectively. It should be noted that the informational content of the TPMs is largely derived from the entry/exit and smaller size classes, which is evidenced by the normalized entropy measure for each row of the matrices, as is presented in the final column of each table. Overall, however, it is clear that the estimated TPMs are, statistically speaking, significantly different from that of the priors and, as such, the data conveys information that merits further analysis. Accordingly, we draw three primary conclusions from the matrices. First, Nicaragua’s agricultural and livestock sector is characterized by overall low probabilities of exit. Moreover, any entry that occurs is into beans and maize pro-

duction and typically into the smallest size class. Thus, while smallholders (i.e. producers with landholdings <2.5 *manzanas* in Table 2.5 and <2.75 *manzanas* in Table 2.6) exhibit an extremely low probability of expansion, such a low propensity to exit coupled with new small-scale entrants suggests stability, if not an increasing prevalence, of small-scale production. Second, there appears, in general, a tendency toward specialization among the larger producers, primarily to that of livestock production. Finally, given the high (low) probabilities associated with transition from (to) the 5-20 (in Table 2.5) and 6.75-18.5 (in Table 2.6) size classes, the land distribution exhibits a moderate tendency toward bifurcation.

Concerning the first conclusion, by looking at the columns of the TPMs that correspond to entry/exit, it is clear that the probabilities associated with exit are very low and frequently zero. For example, looking to the smallest size class in Table 2.6, while livestock producers have an estimated probability of exit of 0.09, beans and maize as well as diversified producers are estimated to continue cultivation with near certainty (i.e. the probability of exit is 0.00). Further, while the probability corresponding to remaining in the entry/exit class is quite high at 0.86 in both tables, the entire mass of the distribution related to entry is concentrated on beans and maize producers, the majority of which falls on the smallest size class (0.09 in both tables). However, for these small-scale producers, a low probability of exit and an influx of new entrants is not accompanied by a high probability of expansion, which, from Table 2.6, is estimated to be 0.10, 0.11, and 0.02 for beans and maize, livestock, and diversified producers, respectively.¹⁷ Thus, with the observed pattern of sectoral entry and strikingly high probabilities of remaining within the smallest size class – 0.90, 0.81, and 0.99 for beans and maize, livestock, and diversified producers, respectively (Table 2.6) – it is relatively safe to conclude that Nicaragua’s agricultural and livestock sector will remain populated by smallholders in the near future.

Moving to the second conclusion, the trend toward specialization or away from diversified production is best seen by summing, for each row in each TPM, across the size

¹⁷The probability of expansion is calculated by simply summing those elements of the relevant row of the TPM that correspond to a transition to a larger size class. To get a sense of the truly low magnitude of these probabilities examine the probabilities of expansion for the next largest size class.

Table 2.5: Transition Probability Matrix (AC Definition)

Entry/Exit		<2.5			2.5-5			5-20			20-50			>50			$S(\tilde{p}_k)$
		BM	L	D	BM	L	D	BM	L	D	BM	L	D	BM	L	D	
Entry/Exit	0.86 (0.34)	0.09 (0.29)	0.00 (0.00)	0.00 (0.00)	0.03 (0.19)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01 (0.00)	0.00 (0.00)	0.00 (0.06)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.18
<2.5	BM	0.81 (0.32)	0.04 (0.19)	0.02 (0.08)	0.13 (0.26)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.26
	L	0.08 (0.23)	0.55 (0.45)	0.01 (0.04)	0.02 (0.08)	0.04 (0.20)	0.03 (0.05)	0.00 (0.00)	0.00 (0.00)	0.01 (0.02)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.49
	D	0.00 (0.00)	0.22 (0.17)	0.05 (0.44)	0.00 (0.02)	0.02 (0.08)	0.01 (0.04)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.35
2.5-5	BM	0.05 (0.05)	0.02 (0.15)	0.03 (0.06)	0.38 (0.41)	0.03 (0.15)	0.09 (0.21)	0.12 (0.29)	0.07 (0.12)	0.10 (0.20)	0.00 (0.02)	0.02 (0.06)	0.01 (0.02)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.77
	L	0.02 (0.09)	0.00 (0.10)	0.04 (0.04)	0.01 (0.01)	0.39 (0.44)	0.07 (0.22)	0.00 (0.00)	0.17 (0.31)	0.06 (0.02)	0.01 (0.01)	0.06 (0.09)	0.04 (0.28)	0.02 (0.13)	0.02 (0.10)	0.09 (0.00)	0.73
	D	0.00 (0.00)	0.00 (0.01)	0.14 (0.24)	0.09 (0.29)	0.11 (0.14)	0.44 (0.45)	0.01 (0.13)	0.02 (0.06)	0.18 (0.31)	0.00 (0.01)	0.01 (0.04)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.07)	0.61
5-20	BM	0.00 (0.02)	0.00 (0.00)	0.00 (0.00)	0.12 (0.13)	0.01 (0.14)	0.03 (0.19)	0.53 (0.35)	0.08 (0.14)	0.06 (0.08)	0.13 (0.29)	0.01 (0.05)	0.00 (0.04)	0.03 (0.14)	0.01 (0.07)	0.00 (0.00)	0.58
	L	0.03 (0.05)	0.00 (0.01)	0.00 (0.02)	0.06 (0.12)	0.02 (0.06)	0.03 (0.10)	0.07 (0.21)	0.42 (0.23)	0.07 (0.13)	0.04 (0.22)	0.03 (0.15)	0.13 (0.18)	0.01 (0.05)	0.09 (0.13)	0.00 (0.00)	0.73
	D	0.00 (0.00)	0.00 (0.00)	0.00 (0.02)	0.06 (0.04)	0.05 (0.15)	0.10 (0.16)	0.16 (0.21)	0.11 (0.25)	0.35 (0.41)	0.06 (0.07)	0.06 (0.25)	0.00 (0.03)	0.00 (0.00)	0.02 (0.07)	0.03 (0.21)	0.71
20-50	BM	0.05 (0.10)	0.00 (0.00)	0.00 (0.00)	0.05 (0.16)	0.02 (0.03)	0.05 (0.12)	0.05 (0.27)	0.01 (0.13)	0.05 (0.00)	0.20 (0.36)	0.09 (0.11)	0.03 (0.15)	0.17 (0.28)	0.23 (0.30)	0.00 (0.00)	0.82
	L	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.04 (0.12)	0.00 (0.00)	0.00 (0.00)	0.02 (0.10)	0.02 (0.06)	0.01 (0.02)	0.02 (0.05)	0.61 (0.43)	0.04 (0.22)	0.00 (0.00)	0.22 (0.32)	0.02 (0.12)	0.50
	D	0.00 (0.01)	0.00 (0.00)	0.00 (0.00)	0.05 (0.04)	0.02 (0.04)	0.00 (0.01)	0.16 (0.21)	0.12 (0.28)	0.02 (0.03)	0.18 (0.34)	0.16 (0.27)	0.19 (0.30)	0.00 (0.00)	0.07 (0.15)	0.03 (0.14)	0.78
>50	BM	0.01 (0.02)	0.00 (0.00)	0.00 (0.00)	0.00 (0.02)	0.10 (0.20)	0.03 (0.07)	0.01 (0.00)	0.03 (0.12)	0.06 (0.24)	0.12 (0.20)	0.11 (0.22)	0.12 (0.24)	0.12 (0.31)	0.19 (0.28)	0.11 (0.24)	0.90
	L	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01 (0.11)	0.00 (0.00)	0.00 (0.00)	0.22 (0.22)	0.01 (0.01)	0.04 (0.16)	0.14 (0.27)	0.04 (0.14)	0.06 (0.21)	0.44 (0.41)	0.04 (0.15)	0.70
	D	0.01 (0.02)	0.00 (0.00)	0.00 (0.00)	0.00 (0.13)	0.03 (0.07)	0.04 (0.06)	0.06 (0.11)	0.07 (0.08)	0.06 (0.00)	0.00 (0.00)	0.15 (0.14)	0.07 (0.16)	0.08 (0.12)	0.20 (0.25)	0.24 (0.25)	0.88

Note: Following Golan et al. (1996, 42), standard errors (in parentheses) are calculated from the information matrix of the dual formulation.

Table 2.6: Transition Probability Matrix (DD Definition)

Entry/Exit		<2.75			2.75-6.75			6.75-18.5			18.5-55			>55			$S(\hat{p}_k)$
		BM	L	D	BM	L	D	BM	L	D	BM	L	D	BM	L	D	
Entry/Exit	0.86 (0.34)	0.09 (0.29)	0.00 (0.00)	0.00 (0.00)	0.04 (0.19)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.06)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.18
BM	0.00 (0.00)	0.82 (0.32)	0.06 (0.19)	0.02 (0.08)	0.10 (0.26)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.25
<2.75	0.09 (0.23)	0.25 (0.36)	0.55 (0.45)	0.01 (0.04)	0.03 (0.08)	0.07 (0.20)	0.00 (0.05)	0.00 (0.00)	0.00 (0.02)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.50
D	0.00 (0.00)	0.23 (0.39)	0.05 (0.17)	0.71 (0.44)	0.00 (0.02)	0.01 (0.08)	0.01 (0.08)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.33
BM	0.02 (0.05)	0.01 (0.05)	0.04 (0.15)	0.02 (0.06)	0.48 (0.41)	0.06 (0.15)	0.10 (0.21)	0.14 (0.29)	0.04 (0.12)	0.08 (0.20)	0.01 (0.02)	0.01 (0.06)	0.00 (0.02)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.67
2.75-6.75	0.04 (0.09)	0.00 (0.00)	0.03 (0.10)	0.01 (0.04)	0.00 (0.01)	0.00 (0.44)	0.44 (0.22)	0.10 (0.00)	0.17 (0.31)	0.03 (0.02)	0.00 (0.01)	0.03 (0.09)	0.12 (0.28)	0.03 (0.13)	0.03 (0.10)	0.00 (0.00)	0.66
D	0.00 (0.00)	0.00 (0.02)	0.00 (0.01)	0.09 (0.24)	0.15 (0.29)	0.05 (0.14)	0.48 (0.45)	0.04 (0.13)	0.01 (0.06)	0.15 (0.31)	0.00 (0.01)	0.01 (0.04)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01 (0.08)	0.58
BM	0.01 (0.02)	0.00 (0.00)	0.01 (0.02)	0.00 (0.00)	0.08 (0.13)	0.07 (0.14)	0.12 (0.19)	0.31 (0.35)	0.07 (0.14)	0.03 (0.08)	0.19 (0.29)	0.02 (0.05)	0.02 (0.04)	0.04 (0.14)	0.03 (0.07)	0.00 (0.00)	0.77
6.75-18.5	0.03 (0.05)	0.00 (0.01)	0.00 (0.01)	0.01 (0.02)	0.07 (0.12)	0.03 (0.06)	0.06 (0.10)	0.13 (0.21)	0.18 (0.23)	0.06 (0.13)	0.14 (0.22)	0.10 (0.15)	0.11 (0.18)	0.02 (0.05)	0.08 (0.13)	0.00 (0.00)	0.87
D	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01 (0.02)	0.02 (0.04)	0.07 (0.15)	0.08 (0.16)	0.10 (0.21)	0.13 (0.25)	0.35 (0.41)	0.02 (0.07)	0.13 (0.25)	0.01 (0.03)	0.00 (0.00)	0.02 (0.07)	0.07 (0.21)	0.73
BM	0.04 (0.10)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.08 (0.16)	0.01 (0.03)	0.05 (0.12)	0.15 (0.27)	0.05 (0.13)	0.00 (0.00)	0.24 (0.36)	0.04 (0.11)	0.05 (0.15)	0.12 (0.28)	0.17 (0.30)	0.00 (0.00)	0.84
18.5-55	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.04 (0.12)	0.00 (0.00)	0.00 (0.00)	0.03 (0.10)	0.02 (0.06)	0.00 (0.02)	0.01 (0.05)	0.62 (0.43)	0.08 (0.22)	0.00 (0.00)	0.17 (0.32)	0.03 (0.12)	0.48
D	0.00 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.02 (0.04)	0.01 (0.04)	0.01 (0.04)	0.10 (0.21)	0.17 (0.28)	0.01 (0.03)	0.22 (0.34)	0.18 (0.27)	0.18 (0.30)	0.00 (0.00)	0.06 (0.15)	0.04 (0.14)	0.73
BM	0.01 (0.02)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01 (0.02)	0.10 (0.20)	0.03 (0.07)	0.00 (0.00)	0.05 (0.12)	0.00 (0.00)	0.11 (0.20)	0.13 (0.22)	0.13 (0.24)	0.15 (0.31)	0.18 (0.28)	0.10 (0.24)	0.91
>55	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.04 (0.11)	0.00 (0.00)	0.00 (0.00)	0.11 (0.22)	0.00 (0.01)	0.06 (0.16)	0.05 (0.27)	0.05 (0.14)	0.07 (0.21)	0.44 (0.41)	0.05 (0.15)	0.75
D	0.01 (0.02)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.10 (0.13)	0.04 (0.07)	0.03 (0.06)	0.07 (0.11)	0.05 (0.08)	0.00 (0.00)	0.00 (0.00)	0.12 (0.14)	0.11 (0.16)	0.05 (0.12)	0.26 (0.25)	0.15 (0.25)	0.90

Note: Following Golan et al. (1996, 42), standard errors (in parentheses) are calculated from the information matrix of the dual formulation.

classes for each use-oriented state. Once accomplished, for each row in each TPM, one is left with a simple probability distribution associated with land use transitions. For both Tables 2.5 and 2.6, the three smallest size classes are most likely to remain in their current state of land use. For example, for the diversified producers in the 2.75-6.75 size class in Table 2.6, the probability of remaining diversified is 0.73, whereas the probability of transitioning to beans and/or maize production is 0.19 and the probability of transitioning to livestock production is 0.07. For larger producers, however, there is an unambiguous movement toward livestock production. Looking again at Table 2.6, it is evident that for each use-oriented state associated with the two largest size classes, with the exception of beans and maize producers in the 18.5-55 class, the most probabilistic outcome is a transition to livestock production. Again, to use an example, for the diversified producers in the largest size class, the probability of remaining in the diversified state is 0.29, whereas the probability of transitioning to livestock production is 0.47. Importantly, these trends are similarly observed in Table 2.5. Therefore, while small- and medium-sized producers will tend to remain in their use-oriented states, the expectation is that larger producers will gravitate toward livestock production.

The third conclusion is more nuanced and not easily inferred directly from the TPMs. To examine the expected changes in the land distribution, as it pertains to each definitional approach, a row vector containing the state data from the most recent period (i.e. 2005) is post-multiplied by the relevant TPM to predict the proportional allocation of producers in a subsequent period.¹⁸ Table 2.7 presents the predicted proportions and, to facilitate comparison, reprints the data from Table 2.4. Aggregating over the use-oriented classes, it is evident that prediction based on the AC definitions estimates that all size classes will see increases in their aggregate proportions, which results from continued depletion of the entry/exit category. Although, it can be shown that the 5-20 class definitively witnesses the slowest rate of growth. Predictions based on the DD definitions are less subtle. While the two smallest and two largest size classes continue to exhibit increasing proportions, the 6.75-18.5 size class displays a moderate decline from 11.84 to 11.52 percent, which is driven

¹⁸This subsequent period corresponds approximately to the year 2009.

Table 2.7: Predicted Proportions

		1998		2001		2005		Pred.	
State		AC	DD	AC	DD	AC	DD	AC	DD
Entry/Exit		24.09	24.09	21.94	21.94	20.61	20.61	18.84 (0.19)	18.71 (0.23)
AC: <2.5	BM	13.66	13.74	11.09	11.09	22.02	22.10	22.46 (9.43)	22.71 (9.95)
	L	6.13	6.13	9.52	9.52	3.06	3.06	3.87 (6.03)	3.93 (6.25)
DD: <2.75	D	11.84	11.84	10.02	10.02	7.45	7.45	6.52 (1.06)	6.48 (1.06)
AC: 2.5-5	BM	6.46	7.37	5.30	6.04	9.11	10.60	9.22 (3.45)	10.28 (4.23)
	L	1.90	2.32	4.47	6.04	2.24	2.73	2.46 (2.43)	3.43 (3.79)
DD: 2.75-6.75	D	6.54	7.78	6.46	7.53	4.22	4.97	4.09 (1.67)	5.14 (1.99)
AC: 5-20	BM	5.63	4.22	3.81	2.81	7.86	5.55	7.02 (3.86)	5.09 (2.50)
	L	2.32	1.82	6.87	4.47	4.30	3.39	5.27 (3.41)	3.44 (1.41)
DD: 6.75-18.5	D	7.78	5.46	6.21	4.55	4.39	2.90	4.38 (1.04)	2.99 (1.03)
AC: 20-50	BM	2.48	2.90	1.99	2.40	3.06	3.89	2.72 (0.99)	3.52 (1.27)
	L	2.24	2.48	3.81	4.72	4.22	4.97	4.69 (0.56)	5.59 (1.01)
DD: 18.5-55	D	2.81	3.97	2.48	3.23	1.24	1.99	1.60 (1.40)	2.25 (1.47)
AC: >50	BM	1.08	1.08	0.99	0.83	1.24	1.16	1.34 (0.22)	1.27 (0.27)
	L	2.57	2.40	3.15	3.06	4.06	3.73	4.57 (0.54)	4.27 (0.55)
DD: >55	D	2.48	2.40	1.90	1.74	0.91	0.91	0.97 (0.81)	0.91 (0.56)
Total		100	100	100	100	100	100	100	100

Note: The standard deviation of the prediction is provided in parentheses.

by the high (low) probabilities corresponding to transitions from (to) beans and maize production at this size class. Consequently, while such a tendency toward bifurcation is not entirely insensitive to definitional changes, the trend becomes readily apparent when using what should be considered the more robust of the two size-oriented definitions. Moreover, given the above-discussed trajectories of the aggregate proportions, this bifurcation is not entirely unexpected.

The state elasticities are presented in Tables 2.8 and 2.9. Immediately evident from these tables is the relative magnitude of the input and output price elasticities. Given the centrality of these variables in the process of structural transformation, it is beneficial to focus the discussion on this fourth and final primary conclusion. Concerning output prices, the prices of rice, cattle, and beans appear most elastic. In both Tables 2.8 and 2.9, a one percent increase in the mean price of rice induces an approximate 18 percent decrease in

the entry/exit state (i.e. net entry). Moreover, with increasing rice prices, the expectation should be that a growing number of producers coalesce around the 5-20 (Table 2.8) and 6.75-18.5 (Table 2.9) size classes, as evidenced by the unambiguously positive elasticities associated with these classes. Even though rice producers fall within the diversified category, there does not appear to be any unique effect on the corresponding classes. As for the price of cattle, in both tables, the elasticities suggest that a percentage point increase in the price of cattle leads to an approximate 8 percent decrease in the entry/exit category. Thus, once again, rising prices are associated with net entry. However, as opposed to the price of rice, increases in the price of cattle generally lead to a concentration of landholdings, especially among livestock producers, which follows from the elasticities associated with the >50 (>55) size class in Table 2.8 (Table 2.9). Lastly, moving to the price of beans, in contrast to the above-discussed elasticities, rising bean prices appear to prompt a moderate net exit from the sector. Further, even though the elasticities show no obvious impact on the land distribution, there does appear to be an inducement of use-oriented transformation as, with increasing bean prices, there is a clear negative impact on diversified categories of all sizes, which occurs independent of the definition used.

With respect to input prices, the agricultural wage is undoubtedly the more elastic. Given the aforementioned theoretical ambiguity of the effect of the agricultural wage on entry/exit, it should first be noted that an increase in the agricultural wage is estimated to lead to a substantial (approximately 21 percent) increase in the entry/exit state (i.e. net exit). Moreover, in both tables, small- and medium-sized bean and maize producers are found to witness relatively large proportional decreases, which implies that these producers are precisely those compelled to exit. Therefore, as opposed to using increasing off-farm wages to subsidize production, such smaller-scale producers are evidently more likely to leave the sector. The agricultural wage also demonstrates an impact on other areas of concern. For example, in both Tables 2.8 and 2.9, increasing wages exhibit a tendency to bring about a concentration of producers in the largest size class as well as generalized increase in diversified production. While the theoretical explanation for the effect of the

Table 2.8: State Elasticities (AC Definition)

	Entry/Exit	<2.5			2.5-5			5-20			20-50			>50		
		BM	L	D	BM	L	D	BM	L	D	BM	L	D	BM	L	D
Land Prod.	-2.52	3.54	0.15	-0.76	0.66	2.10	0.73	0.05	1.32	-2.09	-1.46	-0.06	-1.39	-0.66	-0.29	-2.35
Labor Prod.	1.15	-1.96	3.33	-0.50	-1.47	2.38	-0.87	-4.94	0.30	1.39	-2.26	3.57	2.27	-0.55	1.40	0.87
Ag. Wage	21.34	-31.56	28.77	12.25	-36.54	11.06	2.93	-25.88	-5.50	6.63	20.78	-3.75	11.97	12.35	15.39	6.20
Land Price	0.82	-6.02	0.39	12.18	-1.95	-1.36	0.55	-1.04	-2.43	3.25	-0.06	1.27	-2.02	-3.91	-1.49	0.04
Price of Beans	1.99	-6.46	7.58	-1.67	10.55	11.20	-5.42	2.24	13.02	-19.08	-9.75	3.22	-3.07	11.03	-5.77	-8.60
Price of Cattle	-8.68	17.07	-8.36	-8.31	10.74	-16.68	-5.63	13.41	-12.75	2.36	10.26	-7.50	0.90	0.61	3.36	4.26
Price of Coffee	-1.09	-2.36	9.99	0.08	-5.45	4.59	-1.57	-3.35	-2.41	5.07	6.68	1.30	3.59	-0.41	3.00	-1.33
Price of Maize	3.01	-2.85	0.48	-1.41	0.62	-0.64	3.00	-0.77	-1.89	-0.22	-4.27	-0.51	1.29	-3.55	0.33	2.50
Price of Rice	-18.58	35.58	-52.89	-12.85	29.73	-11.62	-11.44	28.84	12.85	5.77	-15.78	0.75	-0.39	-25.05	-17.66	-3.19
Credit	0.60	-0.46	1.14	0.25	-1.66	-2.39	0.57	-1.33	-0.55	2.92	-0.92	1.16	-1.90	1.43	-2.26	3.82
Title	-2.78	0.22	-3.51	0.77	6.40	0.49	-0.06	4.48	-0.12	-0.23	2.16	-0.09	-2.97	-2.88	1.44	-1.61
Tech. Assist.	1.98	-2.34	0.60	0.54	-2.53	1.12	0.49	-1.50	1.51	0.54	-1.20	-0.82	1.29	0.93	-0.26	0.82
Age	5.09	-5.82	12.88	0.89	-8.39	-1.10	13.61	-8.93	-2.23	-6.46	-5.51	1.64	-6.31	11.67	-1.75	1.19
Education	-2.72	3.35	-0.74	-2.60	2.52	0.58	4.04	-0.15	-0.87	-0.28	0.85	-1.11	-4.06	-1.19	2.89	-2.82

Table 2.9: State Elasticities (DD Definition)

	Entry/Exit	<2.75			2.75-6.75			6.75-18.5			18.5-55			>55		
		BM	L	D	BM	L	D	BM	L	D	BM	L	D	BM	L	D
Land Prod.	-2.60	3.48	-0.10	-0.85	1.36	2.21	1.05	-1.13	0.83	-3.23	-0.64	0.22	-1.49	-0.93	-0.14	-1.79
Labor Prod.	1.13	-2.23	3.83	-0.06	-2.06	1.88	-0.60	-5.87	-0.17	2.50	-2.80	3.07	1.61	-0.23	1.82	1.35
Ag. Wage	20.39	-32.93	30.96	13.90	-35.84	2.66	8.11	-20.47	-3.26	5.22	7.13	-3.87	13.09	11.18	14.69	9.43
Land Price	0.99	-6.13	0.86	12.52	-3.67	-2.13	0.20	0.35	-0.76	6.30	-1.40	0.66	-2.87	-3.38	-1.03	-1.36
Price of Beans	1.55	-7.33	6.89	-1.69	15.16	11.75	-6.91	-4.05	12.08	-17.84	-5.51	2.93	-9.05	14.42	-4.87	-7.16
Price of Cattle	-7.85	17.95	-9.10	-9.39	7.21	-12.96	-5.51	17.69	-11.03	-2.61	10.05	-6.60	3.04	0.15	0.74	6.40
Price of Coffee	-0.93	-2.80	11.00	0.46	-6.83	1.90	-0.02	-0.73	-2.33	6.02	4.64	1.27	3.07	-1.62	1.97	-1.87
Price of Maize	3.18	-2.60	0.44	-1.36	-0.87	-1.66	0.73	-0.24	0.15	1.98	-3.59	-1.72	1.33	-3.46	0.34	4.60
Price of Rice	-17.48	39.01	-56.32	-14.68	27.02	-7.71	-14.99	29.25	9.60	7.19	-1.13	3.38	4.34	-28.70	-17.71	-9.43
Credit	0.59	-0.60	1.37	0.14	-1.62	-1.25	1.72	-1.87	-0.47	1.70	-0.80	0.91	-1.23	1.14	-1.77	3.95
Title	-2.63	0.53	-3.46	0.81	5.41	0.47	0.22	5.07	0.41	-2.07	2.75	0.00	-3.08	-2.68	1.16	-2.74
Tech. Assist.	1.93	-2.40	0.60	0.63	-2.38	1.60	0.21	-0.70	0.45	1.02	-1.21	-0.39	1.39	0.33	-0.34	0.86
Age	4.35	-7.56	14.10	1.12	-3.13	1.84	12.48	-15.76	-4.07	-4.52	-8.81	0.65	-8.28	16.51	0.12	1.92
Education	-2.95	3.56	-1.05	-2.55	3.16	1.09	3.62	-1.46	-0.89	-2.25	1.52	-1.35	-1.81	-3.75	3.30	-3.24

agricultural wage on entry/exit is relatively straightforward, the same cannot be said for its effect on such size- and use-oriented transformation.

In concluding the discussion of the state elasticities, it is necessary to touch upon a few interesting findings with respect to the remaining policy/environmental variables. First, advances in land and labor productivity affect structural change in a dissimilar manner. Whereas developments in land productivity tend to be accompanied by a convergence of producers to the 2.5-5 (Table 2.8) and 2.75-6.75 (Table 2.9) size classes, labor productivity changes influence no clear effect on the land distribution. Conversely, while increases in labor productivity correspond to a distinct movement out of beans and maize production, no such use-oriented transformation is observed for changes in land productivity. Second, in addition to their relative inelasticity, improvements in access to credit, land titling, or the provision of technical assistance do not, in general, affect size- or use-oriented transformation in any perceptible way. The only exception to this statement is that an augmentation of the proportion of producers receiving technical assistance is associated with a general transition to diversified production. Finally, regarding demographics and human capital, the defining characteristic of the associated elasticities is that increases in the average age or education of household heads is accompanied by a clear reduction in the 5-20 (Table 2.8) and 6.75-18.5 (Table 2.9) size classes. It should be noted, however, that this phenomenon is much less pronounced for the case of education.

2.6 Conclusions

In the context of wider debate regarding the impact of globalization and/or liberalization on smallholder agriculture in developing countries, we explored, for the case of Nicaragua, recent trends in the distribution and use of agricultural landholdings, as well as the role agricultural policy and other key factors have played in shaping those trends. Accordingly, two basic research questions were put forth: First, what is the future of smallholder agriculture in Nicaragua? More specifically, what are the relative probabilities of expansion, contraction, and exit of small-, medium-, and large-scale producers? Does such size-oriented transformation entail an analogous transformation in land use or output

composition? Second, what role do policy/environmental variables play in preventing or facilitating such structural transformation in the agricultural sector?

Concerning the future of smallholder agriculture, first, Nicaragua's agricultural and livestock sector is found to be characterized by a net entry of producers, which is largely due to overall low probabilities of exit. Moreover, the entry that occurs is almost exclusively into beans and maize production and typically at a small-scale. As such, while smallholders witness relatively low probabilities of growth, a low propensity to exit coupled with new small-scale entrants implies a persistence of smallholder agriculture. Second, given the high (low) probabilities associated with transition from (to) production on an intermediate scale, the land distribution exhibits a moderate tendency toward bifurcation, which would appear to obscure any immediate relationship between operational landholdings and land productivity. Third, whereas transformation in land use or output composition is quite uncommon among small- and medium-scale producers, there manifests a tendency toward specialization among larger-scale producers, primarily to that of livestock production. Such changes in output composition, at the very least, point toward a dynamism to which smallholders are compelled to adapt. Finally, regarding the role of policy/environmental variables, the pace of structural transformation appears relatively sensitive to changes in input and output prices. Accordingly, the aforementioned results should be interpreted in light of increasing price volatility.

The question, however, remains: If there is no inverse relationship between farm size and productivity, then why is the proportion of producers operating smallholdings persistently large and seemingly rising? Lipton (2009, 2010), citing farm size trends in a wide array of developing countries, considered three candidate explanations: (1) continuing rural population growth where fragmentation occurs via inheritance practices; (2) rising farm productivity, which would enable rural households to subsist on less land; and (3) a preference, when rural households move out of agricultural production, to retain (small) homestead plots so as to mitigate risk via portfolio diversification. In the presence of a direct relationship between farm size and productivity, population growth, technology-induced increases in farm productivity, and/or risk coping strategies would not explain a

trend toward reduced farm size as small landowners could still conceivably gain by joining their farms, or by selling or renting to larger owners. That is, the distinction between ownership and operational landholdings is crucial in overturning the proposed explanations. Thus, it would appear that an inverse relationship between farm size and productivity is the likely driving force behind the observed farm size trends.

But, if there is a genuine inverse relationship, why does so much land remain in large farms? Lipton (2009, 2010), once again, put forth a number of reasonable explanations: (1) capital market imperfections whereby smaller farmers are commonly denied access to credit due to a lack of collateral; (2) interactions between land and other markets through which large farm operators obtain power/prestige as employers, lenders, merchants, or politicians; and (3) laws, administrative guidelines, and social norms (e.g. primogeniture) that serve to impede subdivision. Overall, suggesting the validity of the above phenomena, Lipton contended that the presence of an inverse relationship not only appears consistent with the widespread persistence of large farms, but also offers a credible explanation for the trend toward reduced farm size.

CHAPTER 3

THE INVERSE RELATIONSHIP BETWEEN FARM SIZE AND PRODUCTIVITY

3.1 Introduction

In 2008, *Foreign Affairs* published Paul Collier’s “The Politics of Hunger,” which incited yet another round of debate on the role of farm size in agricultural productivity/profitability. Collier argued that the root cause of the 2007-08 world food crisis was increased global demand due to rapid economic growth in Asia. However, suggesting that “there is nothing to be done about the root cause of the crisis” (70), he contended that the solution must come from a dramatic increase in global food supply. Increasing food supply, according to Collier, involves three politically challenging steps: (1) more commercial agriculture as in the Brazilian model of high-productivity large farms; (2) lifting the European and African bans on genetically modified crops so as to make full use of available technological advances; and (3) a rollback of the subsidies the United States provides domestic biofuel industries (68). Of these three recommendations, the necessity of increased commercial agriculture has been subject to the greatest controversy.

In a letter to the editor, Byerlee and de Janvry (2009) contended that Collier “missed the boat with his anti-smallholder bias . . . [as] a focus on smallholder farming is a proven strategy for accelerating growth, reducing poverty, and overcoming hunger.” Above all, the authors argued that smallholders have proven to be particularly efficient commercial

farmers and accelerating productivity in small-scale agriculture is instrumental to increasing food production as well as reducing poverty. Three primary pieces of evidence were cited: (1) Asia’s “green revolution” was led by smallholders, suggesting that small-scale producers are surprisingly responsive to new technologies; (2) from 1991 to 2001, China doubled its cereal yields based on the output of smallholders while simultaneously reducing rural poverty by an estimated 63 percent; and (3) whereas Brazil nearly matched China’s productivity growth over the same period, the number of rural poor in the country actually increased. As such, Byerlee and de Janvry contended that “promoting smallholder farming is not ‘romantic populism’ but sound economic and social policy.”

In another forum, the Food and Agriculture Organization of the United Nations’ (FAO) *Expert Meeting on How to Feed the World in 2050*, Collier and Dercon (2009) elaborated on the commercial agriculture argument and identified three areas of potential economies of scale: (1) skills and technology; (2) finance and access to capital; and (3) the organization and logistics of trading, marketing, and storage. With respect to skills and technology, the authors contended that large-scale farms are superior when it comes to handling knowledge diffusion and managing adoption risks, as the scarcity of managerial skills, numeracy, and a basic understanding of “science” makes it costly for smallholders to adopt and adapt new technologies. Regarding finance and access to capital, in addition to collateral-based arguments where large farms possess superior access to credit, Collier and Dercon argued that, like any other commercial enterprise, a commercial farm builds “documented and vetted” evidence, such as audited profits and asset valuations that assist the accumulation of reputation, which lowers the transaction costs of finance. Lastly, on the organization and logistics of trading, marketing, and storage, the authors suggested that with persistently high transaction costs in agricultural markets in developing countries, larger-scale private trading and marketing could reduce costs, possibly via vertical integration or at least coordination. Moreover, with globalization and the emergence of supermarkets come increased demands for standardization and certification, an area where the utilization of scale economies may become increasingly beneficial. In short, scale economies are crucial in the face of high transaction costs.

Collier and Dercon's claims were again met with considerable skepticism and perhaps the most comprehensive counterargument was elaborated upon in Wiggins (2009). Agreeing that "[r]elatively few observers doubt that agricultural development is a necessary, if not sufficient, condition for poverty reduction and food security" (3), Wiggins, however, argued that "more farm output can be achieved largely through smallholder development" (15). The basis of Wiggins' argument is found in five areas where smallholder agriculture can be seen to possess a productive advantage. First, there exist diseconomies of scale once the farm grows larger than can be managed and operated by household labor, as household labor is readily available, flexible, and typically self-supervising and motivated to carry out tasks diligently. In contrast, larger farms incur considerable costs in recruiting and supervising labor. Second, farmers operating small plots may possess more detailed knowledge of their soils, topography, drainage, etc., which allows them to work the land more appropriately. Third, small farms may be more resistant to slumps in prices as household labor may be willing to accept lower returns to their labor at times when a commercial farmer would simply go bankrupt. Fourth, large farms, being formal companies, may be subject to regulations that are rarely applied to small farms. Examples of such regulations are the payment of legal minimum wages, provision of housing, education and health care to hired workers and their families, and taxation. Lastly, citing several instances when the implementation of large-scale agriculture failed, Wiggins contended that certain soil types and conditions may simply be unsuited to large-scale machine farming.

Given the time-variant nature of technology, the workings of financial markets, and changes in agri-food systems, it is clear that a resolution of the current debate is heavily contingent on up-to-date empirical work. Here we focus on the case of Nicaragua, which, once deemed "at high risk" of deteriorating food security (FAO 2008), was hit particularly hard by the food crisis and subsequent global economic downturn. Domestic rice prices, for example, soared in 2008 to 129 percent of those in 2007 and, as a result, Nicaraguans witnessed significant changes in consumption patterns (FAO 2009). In this context, in a thorough review of the relevant literature, we first critically examine the widespread empirical finding of an inverse relationship between farm size and productivity/profitability

in developing countries, a phenomenon, it is contended, most reasonably attributed to labor market imperfections or (technical and/or allocative) efficiency differences between small and large producers. After discussing Nicaragua's nationally-representative LSMS-type panel data (for the years 1998, 2001, and 2005), we then elaborate upon a four-stage empirical framework so as to simultaneously investigate the existence and explanation of a robust relationship between farm size and productivity/profitability in Nicaragua's agricultural and livestock sector. Finally, in turning to the results of the analysis, it appears that, while technical and allocative efficiency differences frequently exert a statistically significant impact on alternative productivity/profitability indicators across different samples, the explanatory power of these variables is evidently insufficient to rule out labor market imperfections as the driving force behind the observed inverse relationship.

3.2 The Inverse Relationship

Debate surrounding the relationship between farm size and productivity/profitability is by no means a new phenomenon. Indeed, many empirical analyses would be remiss to ignore the long line of literature that has developed positing an inverse relationship, at least with respect to developing country agriculture. Conceptually, the literature can be divided into three epochs or phases: (1) early analysis of Indian agriculture; (2) the intervening years and cross-country work; and (3) modern inquiry. In what follows, we discuss these three epochs or phases in turn.

3.2.1 Early Analysis of Indian Agriculture

While Chayanov's (1925)¹ "labor-consumer balance" and Schultz' (1964) "poor but efficient" hypothesis were highly influential early assertions of the relative competitive power of peasant family farms, Sen (1962, 1966) "had the unenviable role of doing the initial poking at what has turned out to be a beehive" (Sen 1975, 148). Sen (1962) explored three basic findings of the Indian Ministry of Food and Agriculture's controversial *Studies in the Economics of Farm Management* (SEFM): (1) land productivity was found to decrease

¹The work was translated into English in 1966.

with the size of landholdings; (2) when family labor employed in agriculture was attributed an “imputed” value at the prevailing wage rate, much of Indian agriculture appeared unremunerative; and (3) “profitability” of agriculture increased with the size of the holding, “profitability” being measured by the surplus of output over cost, including family labor imputations.

Formalizing his explanation of the findings, Sen (1966) contended that, with a substantial gap between wage rates outside the peasant economy and the real cost of labor inside, capitalist farms face higher equilibrium labor costs than that of peasant farms, which leads peasant farms to use labor more intensively and, thus, witness greater land productivity. Given the strong and negative correlation between reliance on family labor and the size of landholdings, not only did this “dual labor market” hypothesis provide a plausible explanation for the observed inverse relationship between land productivity and the size of holdings in the SEFM, but it also pointed to substantial methodological issues in those studies. If family farms indeed faced a lower real labor cost, it follows that they applied labor beyond the point where the marginal product of labor equaled the market wage rate and, therefore, experienced a “fictitious” loss for those marginal units. If this “fictitious” loss outweighed profits on units prior to the critical point, such farms would witness an overall “loss.” Further, given the underestimated profitability of family (and, thus, small) farms, a direct relationship between profitability and the size of holdings should be expected. Therefore, Sen argued that the inverse relationship between land productivity and the size of holdings appeared empirically valid, whereas the unremunerative nature of peasant family farms as well as the direct relationship between profitability and holding size were merely the by-product of methodological issues.

Bhagwati and Chakravarty (1969) raised numerous shortcomings with Sen’s explanation, but perhaps the most damaging was the contention that, empirically, the inverse relationship had been found to persist when examining only capitalist farms. Given the incompleteness of Sen’s theory, the authors pursued other hypotheses and came to suggest that a negative correlation between farm size and land quality (i.e. soil fertility as well as area under irrigation) was the most likely candidate. While this fact was not altogether

ignored by Sen, Bhagwati and Chakravarty refuted his rationalization of the phenomenon. Accordingly, the authors put forth an alternative explanation and contended that larger farms may in fact be formulated by the purchase of land undergoing “distress sale” whereby poorer land is sold and higher quality land retained. As a result, even though such purchases could be profit-enhancing, larger farms would possess lower quality land, be characterized by greater fragmentation, and, therefore, witness lower land productivity.

Dissatisfaction remained with the theoretical accounts, which led Srinivasan (1972) to offer yet another alternative hypothesis. In the face of uncertainty due to the vagaries of weather, Srinivasan illustrated theoretically that, in the absence of land quality differences and with equal access to the labor market at a constant wage rate, it may indeed be optimal for smaller farmers to utilize more labor per hectare than larger producers. More concretely, in maximizing expected income, if farmers choose between allocating labor between self-cultivation at an uncertain return and employment at a given wage, those with smaller landholdings should allocate more labor per hectare in self-cultivation if absolute risk aversion decreases and relative risk aversion does not decrease as wealth increases. Given, then, three competing theoretical explanations of the inverse relationship, analysis returned to the empirical realm in order to verify the inverse relationship, determine the validity of the theoretical accounts, and propose some new explanations.

Yotopoulos and Lau (1973) developed and applied an empirical model to test for the relative technical and allocative efficiency of Indian agricultural producers. Estimating a series of profit functions using aggregated SEFM data, the authors noted three primary results: (1) Indian agriculture exhibited constant returns to scale; (2) both small (<10 acres) and large (>10 acres) producers witnessed the same degree of allocative efficiency; and (3) small farms displayed approximately 20 percent greater technical efficiency. Thus, overall, small farmers had higher actual profits, which was largely due to superior technical efficiency. While the results are not inconsistent with an inverse relationship between farm size and land quality, the fact that the authors found no significant differences in allocative efficiency when using market wage rates in the estimation process did cast a shadow over Sen’s “dual labor market” hypothesis. Interestingly, however, differences in

technical efficiency emerged here as a competing explanation for the productive superiority of smallholders.

Noting the issues associated with econometric work on the basis of averages of groups of unequal size, Bardhan (1973) used previously unpublished farm-level data from the SEFM to examine: (1) the inverse relationship between farm size and output per acre; (2) returns to scale; and (3) imperfections in the labor market. As the inverse relationship held in the majority of districts examined, the author suggested that the results were more likely due to an inverse relationship between farm size and other inputs (i.e. labor) rather than scale diseconomies, given that production function estimates suggested that only paddy producing districts showed evidence of diminishing returns to scale. Examining whether the explanation resided in labor market imperfections, Bardhan found that for nearly all districts the estimated value of the marginal product of labor was significantly *higher* than the average wage rate, which again contrasted starkly with Sen's hypothesis, but was shown to be consistent with Srinivasan's model.

A final notable study using farm-level SEFM data is Carter (1984). Investigating the inverse relationship and corresponding explanation in the Indian state of Haryana, Carter found that, controlling for intravillage land quality differences, per-hectare production declined approximately 20 percent as farm size doubled. Given the estimate of constant returns to scale, the author contended that the results were due to the fact that small farms (<10 acres) used far more inputs per hectare than large farms (>10 acres). As labor on small farms was employed 36 percent beyond the optimal level defined by profit maximization at *market* prices, Carter suggested that most likely market prices overstated the actual opportunity cost of the peasant's factors of production (i.e. labor). As such, the analysis favored the "dual labor market" hypothesis.

Largely due to the early work on Indian agriculture, an inverse relationship between farm size and land productivity came to be regarded as a "stylized fact" of traditional agriculture. However, no consensus emerged on the explanation for the phenomenon. As the cumulative result of the theoretical and empirical analysis, five alternative hypotheses can be distinguished: (1) labor market imperfections; (2) land quality heterogeneity; (3)

differential responses to uncertainty; (4) decreasing returns to scale; and (5) efficiency differences. Sen’s “dual labor market” hypothesis found empirical support in Carter’s work, but was refuted by Yotopoulos and Lau as well as Bardhan. Bhagwati and Chakravarty suggested that differences in land quality were the most likely candidate, but Carter contended that this explanation was partial at best. Even though Srinivasan’s model received relatively little attention in the empirical work, the explanation was found to be consistent with the results of Bardhan. Finally, whereas Yotopoulos and Lau, Bardhan, and Carter all rejected decreasing returns to scale, Carter found that differences in technical efficiency may be a possible explanation. Overall, then, as no clear explanation emerged, analysis turned to other countries and, thus, data in search for answers.

3.2.2 The Intervening Years and Cross-Country Work

Illustrating the universality of the inverse relationship, as well as shedding light on its explanation, a few influential cross-country empirical studies surfaced in the 1970s and 1980s. Barraclough and Collarte (1973) provided a qualitative and quantitative analysis of CIDA (Inter-American Committee for Agricultural Development) countries Argentina, Brazil, Chile, Colombia, Ecuador, Guatemala, and Peru. Undertaking an in-depth comparison of *latifundio* (large-scale) and *minifundio* (small-scale) estates,² the authors suggested that both tenure groups used resources wastefully. On the one hand, smallholder labor was said to be overused on small plots and, in many cases, land unsuitable for agriculture (i.e. on hillsides, in gullies, or in deserts) was cultivated so intensively that output per hectare was high even by the standards of modern agriculture. On the other hand, large estates, which were found to incorporate a high proportion of the best soils, possess the most favorable locations (i.e. in close proximity to roads, markets, and water supply), and have greater access to credit and technical assistance, underutilized available resources. On average, only one-sixth of the land in large estates in the seven countries was or had been under cultivation, the rest was left to native vegetation. Further, relative to small-scale

²Even though standardized cross-country definitions remained elusive, *minifundios* were typically defined as sub-family farms that were large enough to provide employment for less than two people whereas *latifundios* were farms large enough to provide employment for over 12 people.

producers, labor was used much less intensively. Overall, then, *minifundios* consistently witnessed much higher average returns per hectare than *latifundios* and the authors suggested that “the combination of rapid population growth, a rigid tenure structure, a paucity of technical aid or capital, and lack of employment alternatives explain the *minifundio*’s high yields from land and low yields from labor” (28).

Solidifying the above findings, Berry and Cline (1979) analyzed “extensive” cross-country data as well as “intensive” data sets for six select countries (Brazil, Colombia, the Philippines, Pakistan, India, and Malaysia) and found that smallholders typically made better use of available land than did larger-scale producers, which was said to result from the greater application of labor per unit of land on small farms. Crucially, the inverse relationship held after removing the influence of land quality as well as when examining “total social factor productivity.” The extension of the inverse relationship to the realm of total factor productivity deserves special mention as “land productivity serves as a shorthand indicator of the influence of farm size on the social efficiency of production” (16). Where the social cost of labor is substantial, the overuse of family labor by small farms implies lower total factor productivity, which dampens the inverse relationship. However, it is clear from Berry and Cline’s study that the inverse relationship was robust to alternative definitions of productivity/profitability in a wide array of countries. As a result, the study has proven to be a highly influential assertion of the competitive power of small-scale producers.

In another influential cross-country study, using data from the FAO’s Farm Management and Production Economics Service, Cornia (1985) found that for a sample of fifteen countries in Africa, Asia, and Latin America³ land yields were significantly higher in small farms for all countries except Bangladesh, Peru, and Thailand.⁴ As the fitting of an unconstrained production function yielded evidence of decreasing returns to scale in only a

³The complete list of countries is as follows: Bangladesh, Barbados, Burma, Ethiopia, India, Korea, Mexico, Nepal, Nigeria, Peru, Sudan, Syria, Tanzania, Thailand, and Uganda.

⁴The author attributed the insignificance of the coefficients for Peru and Thailand as likely due to limited observations. The case of Bangladesh was said to reflect a general weakening of the relationship in land-scarce countries where farm differentiation is limited.

few cases, Cornia suggested that the higher yields were most likely due to a more intensive use of land and higher per hectare resource inputs on small farms. Importantly, the above results were found to decrease in intensity in countries where sufficient job opportunities in the non-agricultural sector were available, which reinforced the centrality of labor market considerations in generating the inverse relationship.

Cornia's analysis is exemplary of the fact that "[b]y far the majority of the studies in the quite substantial body of literature containing empirical production-function estimates reach the conclusion that observed returns are, in fact, nearly constant" (Berry and Cline 1979, 6). Heady and Dillon (1961), Cline (1970), as well as Hayami and Ruttan (1970) were the earliest illustrations of the existence of constant returns to scale in developing country agriculture. As discussed above, Yotopoulos and Lau, Bardhan, and Carter all found constant returns in Indian agricultural production. Accordingly, as the cross-country studies verified, the inverse relationship can rarely be attributed to decreasing returns. So, what bearing do the cross-country studies have on the other explanations? First, Sen's "dual labor market" hypothesis emerged as the most plausible candidate. The relative intensity in the application of labor on small farms observed by Barraclough and Collarte, Berry and Cline, and Cornia points to a relatively low (opportunity) cost of family labor in developing economies. As such, "where conspicuous labor surpluses exist, the superiority of small farming provides solid arguments in favor of land redistribution" (Cornia 1985, 513). Second, differences in land quality across producers, as posited by Bhagwati and Chakravarty, proved unlikely to carry explanatory power outside of India, as Barraclough and Collarte argued that it is larger producers that consistently cultivate the best soils, at least in Latin America. Finally, even though considerations of uncertainty and efficiency received little attention in the cross-country studies, both explanations, as will be seen, received substantial attention in the later literature.

3.2.3 Modern Inquiry

In response to the apparent prevalence of the inverse relationship in developing country agriculture, research on the topic intensified in the mid-1980s. Beginning with theo-

retical developments, although acknowledged in Sen (1966), the fact that a multiplicity of market failures, not merely labor market imperfections, must be invoked to generate a systematic relationship between farm size and productivity was not given formal treatment until Feder (1985). In perhaps the more influential exposition of the phenomenon, Eswaran and Kotwal (1986) modeled an agrarian economy where agents face two primary constraints in their optimization problem: (1) a working capital or credit constraint where access to credit largely depends on the amount of land an agent owns and (2) a time constraint where hired labor is only an imperfect substitute for one's own labor time due to moral hazard. Given such constraints, the authors illustrated the emergence of a fivefold agrarian class structure where the class to which agents belong depends on their initial land endowment. Examining the equilibrium allocation of resources, the authors found land-to-labor ratios to be increasing in land endowments, which implied an inverse relationship between land productivity and land endowments. While the theory is "consistent with the implications of Sen's hypothesis" (489), it is indeed a marked improvement as the inverse relationship was shown to exist independently within different modes of production, which can be viewed as a direct response to the criticism leveled by Bhagwati and Chakravarty (1969).

Building on Srinivasan (1972), Rosenzweig and Binswanger (1993) developed a theoretical framework to explore the relationship between weather risk and agricultural investment portfolios where "farmers choose a set of assets differentially sensitive to weather variability according to their risk preferences and *ex post* abilities to cope with risk" (57).⁵ The authors illustrated that the magnitude of the effect of an increase in weather risk declines with farmer wealth if (1) both absolute and relative risk aversion decline in wealth or (2) wealth facilitates *ex post* consumption smoothing (i.e. through collateral effects wealth influences the ability to access insurance and/or credit markets). Accordingly, wealthy or "large" farmers, even if risk aversion is independent of wealth, may be more willing to undertake risky investments – and, thus, witness greater profitability and productiv-

⁵It is important to note that weather risk is not the only source of risk that has received attention in the literature. Barrett (1996), for example, suggested that differential reactions to price risk can generate the inverse relationship.

ity – in areas where weather risk is sufficiently great, as long wealthier agents are better able to smooth consumption through access to credit and insurance markets. Importantly, the authors substantiated their theoretical claims using India’s ICRISAT data and found that increasing rainfall variability tended to equalize profit rates across wealth classes, even though poorer farmers always witnessed higher profit rates over the sample range of rainfall variability.

As a final theoretical consideration, Kevane (1996) raised two primary issues with the prevailing theoretical work: (1) land ownership is an imperfect proxy for wealth and (2) there are several plausible combinations of factor market imperfections that could not only generate the inverse relationship, but plausibly induce a direct relationship. Accordingly, Kevane developed a typology of models based on pairs of factor market imperfections where land ownership and access to finance were only partially correlated. The sixfold typology is as follows: (1) imperfect labor and land rental markets; (2) imperfect labor and credit markets; (3) imperfect labor and insurance markets; (4) imperfect land rental and credit markets; (5) imperfect insurance and land rental markets; and (6) imperfect insurance and credit markets. The author illustrated that in all cases increases in ownership landholdings and decreases in labor endowments decreased labor-to-land ratios and, thus, land productivity. However, in treating asset ownership as a separate entity, Kevane showed that, while a negative relationship between asset ownership and land productivity prevailed in cases 1-3, a positive relationship emerged in cases 4-6. Suggesting that “[s]uch a positive relationship is more than a theoretical curiosity” (237), using farm-level data from Western Sudan, the author found that wealthier agents indeed obtained higher yields. As a result, Kevane argued that a direct relationship is “likely to arise in settings where households have limited access to financing and reciprocal insurance, and where landlords are reluctant to rent out land for fear of losing property rights” (244).

In another area of development, a series of studies emerged questioning, above all, the treatment of land quality in previous empirical work.⁶ Bhalla and Roy (1988), utilizing

⁶Bias associated with omitted land quality has not been the only specification issue raised. Lamb (2003) contended that mismeasurement or misreporting of farm size may bias estimates, especially in a fixed

detailed data on soil characteristics from India's Fertilizer Demand Survey (FDS), reported three primary results: (1) agro-climatic and soil factors were important determinants of farm productivity; (2) when taking these factors into account, the inverse relationship was observed to weaken and, in some cases, disappear; and (3) the weakened inverse relationship was not found to be due to the advent of the green revolution. After establishing a robust negative correlation between land quality and farm size in India, the authors argued that areas with high rainfall and inherently high land productivity are plausibly more densely populated and, thus, characterized by smaller landholdings.⁷ Accordingly, when explicitly accounting for such factors, the inverse relationship dissipated.⁸ While the relationship held in some regions of India, Bhalla and Roy suggested that their results could not be used to assert that labor market imperfections were indeed absent. Further, as the analysis pertained to survey data collected nearly a decade after the advent of the green revolution, the authors argued that differential adoption of new technologies was an unlikely explanation as there was no systematic relationship between the "progressivity" of given region and the nature of the inverse relationship.

Taking an alternative approach to examining the influence of omitted land quality on the inverse relationship, Benjamin (1995) employed instrumental variable techniques using data on rice farmers from rural Java. While OLS regressions confirmed an inverse relationship between yields and area harvested, the relationship disappeared altogether when instrumenting for area harvested.⁹ The author contended that the results suggested a negative correlation between unobserved land quality and area harvested, which led OLS regressions to suffer from omitted variable bias. Thus, "if farms were subdivided through inheritance over time, egalitarian motives on the part of the benefactor would result in

effect framework. Kimhi (2006) argued that crop composition effects may bias estimates if small farms are more heavily involved in the cultivation of high-valued crops.

⁷Note here the explanation of the negative correlation contrasts with that put forth in Bhagwati and Chakravarty (1969).

⁸See Carter (1984) for similar results.

⁹The instruments employed were population density, presence of a city, and the number of males and females between 10 and 15 years of age.

higher quality parcels being divided more often than low quality parcels. This would impart a negative correlation between farm size and farm quality” (65). Overall, then, Benjamin contended that conventional explanations of the inverse relationship (i.e. labor market imperfections) found little empirical support in rural Java.

In a final area of development, a new body of empirical work emerged signaling a shift from the narrow examination of partial factor productivity differentials to wider notions of profitability differences. Utilizing data from two regions of South Africa¹⁰ and following the “market imperfections” framework laid out in the widely-cited Binswanger et al. (1995), van Zyl et al. (1995) examined the relationship between farm profit rates and operational landholdings while controlling for land quality differences, family labor endowments, and collateral effects associated with ownership landholdings.¹¹ Finding a robust negative relationship between operational landholdings and profitability, the authors argued that supervision and transaction costs associated with hired labor on large farms were the likely cause of the inverse relationship.

Heltberg (1998), employing panel data from the Pakistan Rural Household Survey, modified the “market imperfections” framework in three ways: (1) to account for issues associated with imputing wage rates to family labor, the author employed a variety of specifications of the dependent variable;¹² (2) to capture non-linearities, a third-degree polynomial form for operational landholdings was included; and (3) to examine risk considerations, the coefficient of variation of per capita real income was introduced into the specification. Examining farm value added within a fixed effect framework, the parameter estimates on operational landholdings implied a negative and convex relationship,¹³ which was said to be consistent with a supervision constraint. The coefficient on owned

¹⁰The two regions were Ruens and Vaalharts.

¹¹Due to substantial correlation between ownership and operational landholdings, the authors specified ownership landholdings as the percentage of operational landholdings owned by the operator.

¹²Three primary dependent variables were utilized: (1) farm value added per acre (crop and livestock output less all cash inputs); (2) return to owned land (farm value added plus rental payments received for land rented out); and (3) crop profits (the value of crop production less cash inputs and family labor valued at market wage rates).

¹³The inverse relationship was effective for nearly 90 percent of farms in the sample.

landholdings¹⁴ was positive and highly significant, in line with the hypothesized collateral effect. Finally, the coefficient of variation of income, which could only be included in a random effect model due to its time-invariant nature, displayed a negative and significant impact on farm value added, which implied imperfections in credit and insurance markets. Overall, “the market imperfections framework conform[ed] well with the data” (1824).

Deininger et al. (2003) estimated a variant of the above model based on a 1998-99 survey of Nicaraguan agricultural producers administered by Nicaragua’s Ministry for Agriculture and Forestry (MAGFOR). The study found that the size of operated landholdings displayed a negative and significant impact on profits per *manzana*,¹⁵ which was suggested to result from the fact that “increasing operational size would require farm operators to either reduce the intensity of cultivation or to resort to wage labor which is more difficult to supervise” (1395). While labor market imperfections were said to generate the inverse relationship, it was argued that imperfections in land and credit markets prevented the equalizing of factor ratios across producers. Finally, it is important to note here that a lack of panel data implied that the authors could not eliminate certain unobservable effects (e.g. land quality).

While the above empirical work represents a clear methodological advancement, developments in stochastic frontier and data envelopment analysis have provided a means to an alternative examination of the relationship between farm size and technical as well as allocative efficiency. Even though “most frontier studies have focused only on technical efficiency . . . [and a] limited number of studies [report] an analysis between farm size and efficiency” (Bravo-Ureta and Pinheiro 1993, 98–99), there are a few important works that deserve mention. Bravo-Ureta and Pinheiro (1997), using data on sixty peasant farmers in the Dajabon region of the Dominican Republic, employed stochastic frontier analysis and exploited the self-dual nature of the Cobb-Douglas production function to decompose profit

¹⁴As in van Zyl et al. (1995), this was operationalized as the ratio of owned to operated landholdings.

¹⁵Profits were calculated by subtracting the cost of variable inputs from the value of total output. Household labor was valued at the local wage rate. Also, note that 1 *manzana* = 0.70 hectares.

efficiency into its constituent elements (i.e. technical, allocative, and economic efficiency).¹⁶ Then, utilizing a two-limit tobit procedure the authors examined the relationship between farm size and each type of efficiency, and found that medium-sized farmers (those operating between 3.25 to 6.5 hectares) were the most technically, allocatively, and economically efficient.¹⁷

In another study on Nicaraguan agriculture, Abdulai and Eberlin (2001) employed stochastic frontier analysis to examine technical efficiency in maize and bean farmers using cross-sectional data from two administrative regions.¹⁸ While the authors did not specifically examine the relationship between farm size and technical efficiency, two findings are of particular interest: (1) constant returns to scale characterized both maize and bean cultivation and (2) family size and access to credit displayed a positive and significant impact on technical efficiency. Accordingly, producers heavily reliant on family labor (i.e. small farms) likely witness greater technical efficiency. However, such efficiency gains may be partially offset by a lack of access to credit as small-scale producers are less likely to possess the necessary collateral.

In a final study particularly relevant to Collier's argument, Helfand and Levine (2004) employed data envelopment analysis to explore the relationship between farm size and technical efficiency in the Center-West of Brazil. Using agricultural census data and controlling for land quality differences, land tenure, composition of output, access to institutions/public goods, as well as technology and inputs, the authors found a U-shaped relationship between farm size and technical efficiency. As technical inefficiency increased for farms up to 1000–2000 hectares and fell thereafter, the authors suggested that the inverse relationship broke down at this point as the largest farms in the sample witnessed preferential

¹⁶A producer is fully profit efficient if, and only if, that producer is technically, allocatively, and scale efficient (Forsund et al. 1980). However, under constant returns to scale, scale efficiency is irrelevant. Further, note that economic efficiency is simply a composite (i.e. the product) of technical and allocative efficiency.

¹⁷While the coefficient on farm size was statistically significant in the allocative and economic efficiency regressions, it was insignificant in the technical efficiency model.

¹⁸The regions encompassed the following municipalities: El Jicaró, Jalapa, Nandaime Diria, Dirioma Rivas, and Tola.

access to institutions and services (e.g. rural electricity, technical assistance, and access to markets) as well as displayed more intensive use of the technologies and inputs that raise productivity. Thus, even in a region characterized by rapid modernization, “if one could create an environment in which small to medium size farms had equal access to productivity enhancing institutions, and improved access to modern technologies and inputs, then these farms could still produce more efficiently than farms in the 2000–20,000 ha range” (249).

Overall, then, the era of modern inquiry represents substantial developments both theoretically and empirically. The works of Eswaran and Kotwal, Rosenzweig and Binswanger, and Kevane extended earlier theoretical insights to explicitly incorporate the fact that a multiplicity of market failures must be invoked to generate a systematic relationship between farm size and productivity. While imperfections in labor and credit markets, according to Eswaran and Kotwal, likely induce an inverse relationship, Rosenzweig and Binswanger as well as Kevane contended that other configurations of market imperfections could generate a direct relationship. Incorporating the theoretical insights and taking into account the criticisms leveled by Bhalla and Roy as well as Benjamin, recent empirical work has indeed favored the continued existence of an inverse relationship. Yet, no clear explanation for the phenomenon has emerged. Heltberg (1998) suggested that, as previous studies have persistently found constant returns to scale in farming operations, two competing explanations remain: (1) efficiency differences between large and small farmers (e.g. Bravo-Ureta and Pinheiro [1997], Abdulai and Eberlin [2001], or Helfand and Levine [2004]) and (2) asymmetric market imperfections (e.g. van Zyl et al. [1995], Heltberg [1998], or Deininger et al. [2003]). While both explanations have clearly found empirical support, no investigation has yet examined these explanations in tandem. Specifically, the question remains: Do asymmetric market imperfections continue to hold explanatory power when controlling for efficiency differences between large and small farmers? Before elaborating upon the methodological approach employed to examine this question, it is beneficial to discuss the data used in the analysis.

3.3 Data

Nicaragua's *Encuesta Nacional de Hogares Sobre Medición de Nivel de Vida* (EMNV) is a nationally-representative living standards measurement survey that contains detailed information regarding household characteristics, individual-level demographic traits, health and education levels, household expenditure and income information, as well as considerable data on agricultural and livestock production. The EMNV is panel in nature and consists of 4,209, 4,191, and 6,879 observations in the years 1998, 2001, and 2005, respectively. Of the households surveyed, not all were involved in agricultural or livestock production. As such, the sample is restricted according to the dual criteria that included households reported operating land for agricultural and/or livestock purposes as well as reported non-zero revenue from those activities,¹⁹ which leaves 1,385, 1,491, and 2,867 observations across the three years.

The EMNV is then an unbalanced panel. Of the 5,743 observations, there were 3,813 distinct households surveyed, where 640 households were surveyed in all three years, 650 were surveyed in two of the three years, and the remainder were only surveyed once. Based on the population census of 1995, the 1998 survey sampled the population by (1) random selection of census segments (50-60 households per segment) with probabilities of selection proportionate to population size and (2) random selection of a fixed number of households in each segment (12 in urban segments and 10 in rural segments). The 2001 sample included all households surveyed in 1998 that remained within their respective segment, any households that did not respond to the 1998 survey, as well as a number of new households, which were selected in proportion to population growth. The 2005 survey took a similar approach, but selection of new households was based on the 2005 population census. All data, unless otherwise noted, was compiled and disseminated by the FAO's Rural Income Generating Activities (RIGA) project (RIGA 2011).

¹⁹There are a few households in the sample that reported land operated but no revenue. The decision was made to drop these households for the simple reason that revenue is a crucial variable in the analysis and requires logarithmic transformation for the production frontier. This is not possible with zero values. With uncertainty regarding the reason for the zero values, dropping the households is preferable to some arbitrary scaling of the revenue variable. Only 21, 11, and 9 households in 1998, 2001, and 2005, respectively, were dropped as a result of the revenue criteria.

Of specific interest are the agriculture/livestock modules of the respective surveys. Each year of administration collected comprehensive information regarding the value of output, size of landholdings (both owned and operated), quantity of household and hired labor utilized, value of agricultural/livestock assets, as well as expenditure on seeds, fertilizers, pesticides, etc., among other information. Table 3.1 defines all variables relevant to the analysis and Table 3.2 reports descriptive statistics by year. Unless noted otherwise, all variables reported in value terms are normalized by a producer's (output) price index²⁰ (base year 1998) derived from data available through the FAO's FAOSTAT (FAO 2011a). To get an understanding of the sample, as well as the Nicaraguan agricultural/livestock sector, it is beneficial to highlight some of the statistics.

Table 3.1: Variable Definitions

Variable	Definition
Age	Age of the household head
Assets	Value of agricultural and forestry assets (plows, tractors, trucks, and seeding, harvesting, fumigation, and irrigation equipment) as well as the value of livestock (cattle, pigs, horses, poultry, etc.) (<i>córdoba</i>)
Distance to Health Center	Distance to nearest health center (kilometers)
Education	Years of education of the household head
Farm Value Added	The total value of output less all cash expenditures where cash expenditures includes agricultural and forestry (i.e. land rental, hired labor, seeds, fertilizer, pesticides, etc.) as well as livestock outlays (i.e. feed, medical, enclosure, etc.) (<i>córdoba</i>)
Female	Gender of the household head (Female=1)
Female Labor	Number of female household members between the ages of 14 and 60

Continued on Next Page . . .

²⁰The commodities included in the index are those with price and quantity data available in each year in question. The list of goods is as follows: bananas, beans, cabbages, cassava, cattle meat, chicken meat, cocoa beans, coffee, cow milk, fresh fruit, goat meat, groundnuts, hen eggs, horse meat, maize, pig meat, pineapples, plantains, potatoes, rice, seed cotton, sesame seed, sheep meat, sorghum, soybeans, tobacco, and tomatoes. The index is a Fisher index, which is calculated as the geometric mean of the Laspeyres and Paasche indexes (see Coelli et al. [2005] for the specific calculation).

Table 3.1 – Continued

Variable	Definition
Government Programs	Number of federal or local government programs from which the household benefits
Hired Labor	Days of hired labor employed for agricultural or livestock production
Household Labor	Days of household labor employed for agricultural or livestock production
Indigenous	Indigenous household as determined by the native language of the household head (Indigenous=1)
Male Labor	Number of male household members between the ages of 14 and 60
Married	Marriage status of the household head (Married=1)
Municipality Wage	Median reported daily wage by municipality (<i>córdoba</i>)
Operated	Land owned plus land rented, borrowed, or sharecropped <i>from</i> others less land rented, borrowed, or sharecropped <i>to</i> others (<i>manzanas</i>)
Other Variable Inputs	Value of agricultural (seeds, fertilizer, pesticides, etc.) and livestock inputs (feed, medical, enclosure, etc.) (<i>córdoba</i>)
Owned	Quantity of cultivable land, pastureland, or forestland owned (<i>manzanas</i>)
Per Capita Consumption	Yearly household consumption divided by the reported number of household members (<i>córdoba</i>)
Share	Share of income from wage labor, off-farm self-employment, and non-labor sources (remittances, pensions, interest, etc.)
Value of Output	The value of output is the sum of revenue from agricultural and livestock production. Agricultural revenue includes the sale of crops and crop by-products, the value of own crop consumption as well as sales and the value of own consumption from forestry production. Livestock revenue includes the sale of livestock and livestock by-products as well as the value of own livestock consumption (<i>córdoba</i>).

Table 3.2: Descriptive Statistics by Year

Variable	1998		2001		2005	
	Mean	SD	Mean	SD	Mean	SD
Age	46.31	15.73	47.43	15.70	47.03	15.82
Assets	5,510.57	8,663.81	9,422.76	15,041.39	11,272.08	20,279.45
Distance to Health Center	5.04	5.98	6.20	9.58	5.54	7.42
Education	2.20	3.00	2.27	3.09	3.33	4.01
Farm Value Added	4,708.00	5,160.44	7,177.56	7,302.92	10,165.07	11,896.11
Female	0.11	0.32	0.13	0.33	0.23	0.42
Female Labor	1.42	0.96	1.51	0.99	1.44	0.99
Government Programs	0.93	1.00	1.26	1.46	1.40	1.32
Hired Labor	39.85	110.65	40.16	128.15	45.59	124.78
Household Labor	352.23	241.19	357.71	235.65	579.78	314.16
Indigenous	0.03	0.17	0.04	0.20	0.06	0.25
Male Labor	1.58	1.04	1.64	1.12	1.43	1.06
Married	0.46	0.50	0.47	0.50	0.41	0.49
Municipality Wage	28.44	8.73	36.07	9.18	36.53	7.77
Operated	14.17	26.02	12.57	21.71	14.49	24.23
Other Variable Inputs	563.88	838.92	509.12	697.08	631.10	840.41
Owned	18.05	39.65	15.63	33.45	18.29	38.71
Per Capita Consumption*	4,513.04	5,576.06	5,492.36	5,242.95	7,206.57	6,509.62
Share	43.66	45.09	49.48	39.90	49.27	38.72
Value of Output	6,726.41	6,457.24	10,170.59	9,858.94	11,198.62	12,468.50
<i>N</i>	1,385		1,491		2,867	

*Per capita consumption is in nominal terms.

While per capita consumption is not used in the analysis, it provides a useful starting point. The EMNV defined the national poverty line at 4,259 (2,246), 5,157 (2,691), and 7,155 (3,928) *córdoba* for the years 1998, 2001, and 2005, respectively (extreme poverty line in parentheses). With mean nominal per capita consumption at 4,513, 5,492, and 7,207 *córdoba*, it is clear that the average household hovers just slightly above the national poverty line. However, sample means do not tell the entire story as 65 (27), 63 (24), and 66 (26) percent of the sample fall below the poverty line in the respective years (percent below extreme poverty line in parentheses). Thus, while both the value of output and farm value added trend definitively upwards from 1998 to 2005, it appears poverty remained quite prevalent among agriculture and livestock producers.

Looking to the share of income from off-farm activities (i.e. Share), it can be seen that the incomes of the sampled households, on average, were not solely derived from agricultural and livestock production. However, those activities did provide a large share of total income, being 56, 51, and 51 percent in each year.²¹ Given the central role of agriculture and livestock production (and, of course, the objective of the analysis), it is of most importance to touch upon the land endowments of the sampled households. Kernel density estimates of both land owned and land operated are provided in Figures 3.1 and 3.2. With mean land owned at 18.05, 15.63, and 18.29 *manzanas* and mean land operated at 14.17, 12.57, and 14.49 *manzanas*²² for 1998, 2001, and 2005, respectively, it would appear that the average household possesses a non-negligible quantity of land. Again, however, the sample means can be misleading here as 60 (56), 57 (55), and 56 (54) percent of households owned (operated) less than five *manzanas* in each year, respectively. Therefore, a relatively small number of large farms push mean land owned and mean land operated definitively upward. Importantly, similar trends are observed when examining the value of agricultural/livestock assets possessed (i.e. Assets).

As a final data consideration, household demographic characteristics deserve brief mention. The typical household head is, as expected, male, age 45-50, and non-indigenous. It is also apparent from the descriptive statistics that the observed education levels are quite low, with averages of 2.20, 2.27, and 3.33 years for each survey year. Moreover, 51, 49, and 41 percent of household heads reported no education whatsoever. Therefore, overall, a few defining characteristics of the sample emerge: the typical Nicaraguan agricultural/livestock producer (1) falls below the national poverty line and sometimes far below; (2) possesses only a relatively small plot of land (frequently below five *manzanas*); (3) has little productive assets with which to work; and (4) has had minimal education. With this in mind, it is necessary to turn to the methodological framework.

²¹The share of income from agriculture and livestock activities is simply one minus the share of income from off-farm activities.

²²1 *manzana* = 0.70 hectares.

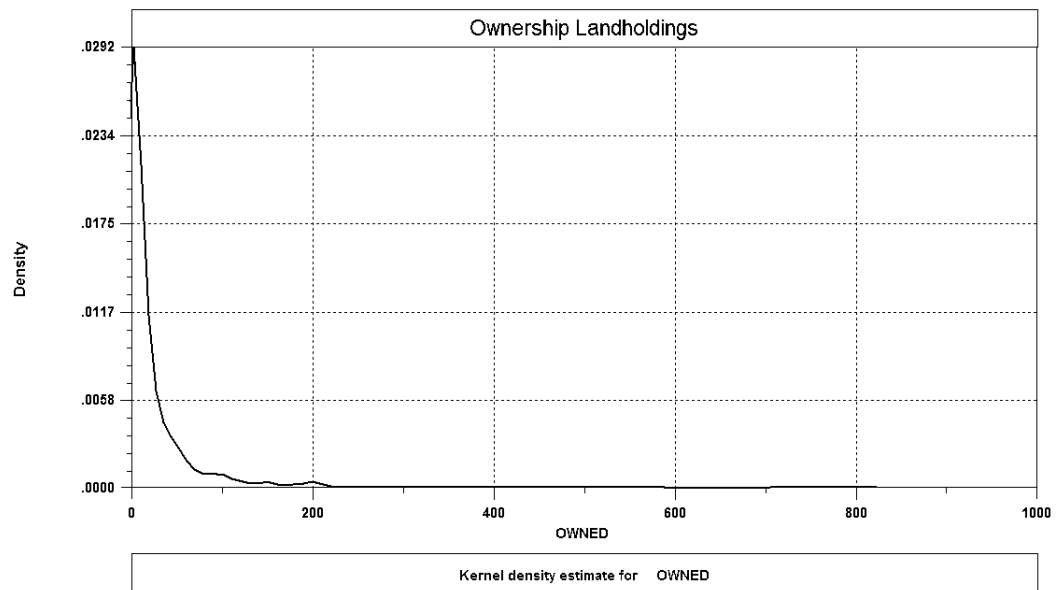


Figure 3.1: Kernel Density Estimates for Land Owned

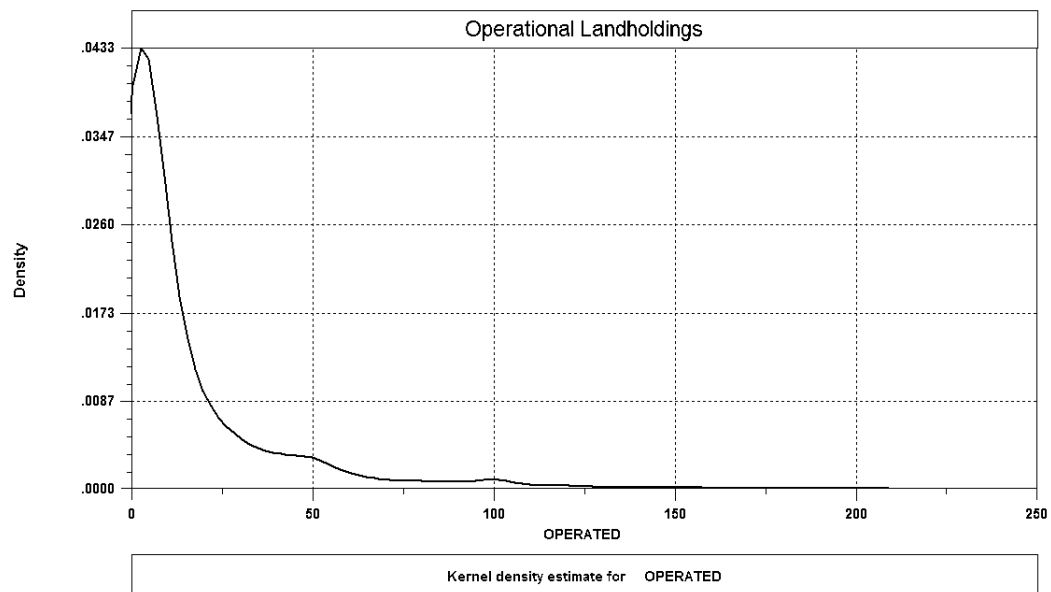


Figure 3.2: Kernel Density Estimates for Land Operated

3.4 Methodology

As the goal of the analysis is to determine whether asymmetric market imperfections continue to hold explanatory power when controlling for (technical and allocative) efficiency differences between large and small farmers, a methodological framework is required that permits robust conclusions to be drawn while staying within the confines of the available data. Barrett et al. (2008) developed a method for estimating structural labor supply models in the presence of unobservable wages and deviations of on-farm marginal revenue product of labor from shadow wages (i.e. allocative inefficiency). While the estimation of structural labor supply models is not of primary interest, the methodology employed by the authors does provide an adequate framework through which to explore the present research question. Their framework can be summarized in four distinct steps. First, use data on all households to fit a production frontier from which observation-specific estimates for the marginal revenue product of labor are derived. Second, with the subsample of households that participated in both wage labor and (on-farm) self-employed labor, calculate allocative inefficiency, where $AI_{it} = \ln(w_{it}/MRP_{Lit})$ and where w_{it} denotes the observed wage from off-farm wage labor and MRP_{Lit} is the marginal revenue product of on-farm labor, both of which are for the i^{th} producer at time t . Third, employing Heckman's two-step procedure, impute allocative inefficiency estimates for households not participating in wage labor and with the estimates calculate the shadow wage for those households as $w_{it}^* = \exp(AI_{it}) \cdot MRP_{Lit}$. Finally, estimate the structural labor supply model using shadow wages and shadow income by instrumental variable methods.

The above framework clearly needs to be adapted to the research question at hand. The tailored methodology is also composed of four different components/steps. First, in order to motivate the analysis as well as maintain comparability with earlier studies, we begin with a simple examination of the farm size-productivity relationship using the "market imperfections" framework discussed above. Second, regarding technical efficiency, a production frontier is fit with exogenous determinants of technical inefficiency (i.e. farm scale and other producer characteristics), which procures technical efficiency estimates as

well as distinct conclusions regarding the relationship between farm scale and technical efficiency. Third, with respect to allocative efficiency, the parameter estimates from the frontier are used to calculate the marginal revenue product of labor for each household and, for those producers that participated in wage employment, allocative inefficiency is calculated using the steps and definitions employed by Barrett et al. (2008). Using Heckman’s two-step procedure, the estimates of allocative inefficiency are regressed on farm scale and other producer characteristics, a regression from which we draw conclusions regarding the relationship between allocative efficiency and farm scale as well as impute allocative inefficiency estimates for households not participating in wage labor. Finally, using the estimates of technical and allocative efficiency obtained, we return to the “market imperfections” framework so as to examine whether technical and allocative efficiency present a valid source of omitted variable bias. What follows is an elaboration of the above steps.

3.4.1 Market Imperfections Framework

Originally developed by Binswanger et al. (1995) and extended by van Zyl et al. (1995) as well as Heltberg (1998), the “market imperfections” framework consists of the estimation of the following simple model:

$$y = f(OW, OP, H, Z) \quad (3.1)$$

where y represents alternative productivity, profitability, or input variables (further discussed below), OW is the amount of owned land, OP denotes the size of the operated holding, H represents labor endowments, and Z is a vector of other exogenous variables influencing the chosen dependent variable. In line with the previous theoretical and empirical work, the expected signs on the parameters of primary importance are as follows: (1) $f'_{OW} > 0$ as a greater quantity of owned land relaxes the credit constraint; (2) $f'_{OP} < 0$ as more operated land exacerbates the supervision constraint; and (3) $f'_H > 0$ as additional family workers relaxes the supervision constraint. Importantly, the above model is a multi-ple correlation as land rental decisions, embodied in the difference between ownership and

operational landholdings, cannot be considered exogenous. Therefore, the parameter estimates represent partial correlation coefficients that illustrate the impact of the regressors for a given level of the other right-hand side variables (Heltberg 1998).

Given the central role of the above specification in the analysis, it is necessary to elaborate upon three primary specification issues. First, omitted variable bias is potentially problematic as variables such as land quality, the household's farming skills, preferential access to markets, etc. are unobserved. As such variables are reasonably time-invariant, these omitted variables can be modeled as household-specific constant terms (i.e. through the estimation of a fixed effect model). However, it should be noted that the fixed effect specification is not immune to omitted variable bias that arises from the exclusion of time-variant regressors (further discussed below). Second, while much of the literature on the inverse relationship has employed land productivity as the dependent variable of interest, this is not entirely satisfactory given that land productivity is only a partial measure of productivity. "Land is not the only scarce resource, and for researchers and policy makers concerned with overall resource efficiency (or total factor productivity), the relationship between agricultural *profitability* (at social or market prices) and the scale of operations is more relevant" (Heltberg 1998, 1817). However, the definition of profitability in traditional agriculture is inherently problematic as it requires imputing the value of family labor whose opportunity cost of time is notoriously difficult to estimate. Given that the valuation of family labor at market wage rates results in estimated losses for approximately 64 percent of observations in our sample, it appears that such imputations overestimate the opportunity cost of family labor and, thus, bias measures of farm profit. Accordingly, in addition to employing land productivity as a dependent variable in the above, farm value added (or return to household labor) is utilized as the profitability metric of choice (see Table 3.1 for a complete definition). Finally, as discussed, Binswanger et al. (1995) contended that since labor supervision costs vary with the quantity of land operated while credit constraints vary with the quantity of land owned, the separate effects of operational and ownership holdings should be distinguished. However, it is necessary to mitigate the raw correlation between these variables so as to avoid multicollinearity issues. As in van Zyl et al. (1995),

then, land owned is operationalized by the percentage of land operated that is owned. This reduces the correlation coefficient from 0.61 to 0.03 while theoretically capturing the desired phenomenon.

In light of the above, the empirical model is as follows:

$$y_{it} = \alpha_i + X'_{it}\beta + \varepsilon_{it}, \quad (3.2)$$

which is estimated for three alternative dependent variables: (1) land productivity (i.e. the total value of output per unit of land operated); (2) farm value added per unit of land operated; and (3) labor usage per unit of land operated (where total labor usage is the sum of the days of household and hired labor employed). The first two dependent variables follow immediately from the above discussion, but the third merits brief elaboration. As labor market imperfections are manifest empirically in relatively greater labor usage per unit of land operated on small farms – due to a relatively low shadow price of labor – a robust inverse relationship between this dependent variable and operational landholdings would theoretically substantiate the labor market imperfections hypothesis. Thus, in general, the examination of the relationship between operational landholdings and the three dependent variables is a means of assessing the sensitivity of the results to alternative specifications.

Regarding the right-hand side of Eq. (3.2), α_i is a household-specific constant and X_{it} includes time dummies (to account for technological change), land owned divided by land operated, land operated (fit with a third-order polynomial to capture non-linearities), male and female labor endowments, and the share of income from off-farm activities (to control for involvement in agriculture).²³ Finally, in an attempt to mitigate output composition effects, the analysis throughout is conducted not only with all producers in the sample, but also with subsamples of beans and maize as well as diversified producers.²⁴ Observations

²³A number of alternative regressors were initially included in the model (e.g. number of plots, area under irrigation, receipt of technical assistance, etc.), but their insignificance gave way to the more parsimonious specification employed here.

²⁴The choice of subsamples draws inspiration from the typology of rural Nicaraguan producers laid out in Deininger et al. (2003). Based on primary income sources, the authors developed a fourfold categorization of rural Nicaraguan producers: (1) livestock ranchers; (2) coffee growers; (3) bean and maize cultivators; and (4) diversified/other farmers. Given the aggregative nature of the diversified/other category and a

were designated to the beans and maize subsample if greater than 50 percent of the value of their output was derived from those activities. The remaining producers were grouped into the “diversified” category (i.e. the subsamples are mutually exclusive).²⁵ While a more disaggregated approach is perhaps desirable, data limitations render this unfeasible. With this first stage as motivation, then, we turn the estimation of technical and allocative efficiency.

3.4.2 Technical Efficiency: Stochastic Frontier Analysis

Development of the stochastic frontier production function is typically attributed to Aigner et al. (1977) as well as Meeusen and van den Broeck (1977) for their independent proposals of the following model:

$$\ln y_i = X_i' \beta + v_i - u_i. \quad (3.3)$$

The deterministic portion of the above equation represents a production function (frequently specified as Cobb-Douglas or translog) where X_i is a $K \times 1$ vector of inputs for the i^{th} producer that is mapped to the (logarithmic) output measure y_i . The interesting aspect of the equation pertains to the dual nature of the error term. The error component v_i represents a symmetric disturbance, which is assumed to be independently and identically distributed $N(0, \sigma_v^2)$. The error component u_i (the inefficiency component) is assumed to be distributed independently of v_i and satisfy $u_i \geq 0$. There are numerous tenable distributions for the one-sided term, but commonly it is assumed to be distributed $N^+(0, \sigma_u^2)$ (i.e. half-normal where “+” denotes truncation from below at zero) or $N^+(\mu, \sigma_u^2)$ (i.e. truncated normal). Aigner et al. (1977) estimated the half-normal model via maximum likelihood techniques where the density function was simply the product of the individual density

relatively small number of observations on coffee and livestock growers, the decision was made to confine the subsample analysis to the aforementioned categories.

²⁵See Berry and Cline (1979) for a similar approach. Also, note that once a producer is classified into a given category their total output value is included in the dependent variable.

functions of v and u , expressed as the joint density of ε and u (where $\varepsilon_i = v_i - u_i$), and then, lastly, u was integrated out to provide the marginal density of ε .

Given the information derived from maximum likelihood estimation, it is necessary then to predict u_i . Jondrow et al. (1982) developed the following:

$$E(u_i|\varepsilon_i) = \sigma^* \left[\frac{\phi(\varepsilon_i\lambda/\sigma)}{1 - \Phi(\varepsilon_i\lambda/\sigma)} - \left(\frac{\varepsilon_i\lambda}{\sigma} \right) \right] \quad (3.4)$$

where $\sigma^* = \sigma_v\sigma_u/\sigma$, $\sigma = \sqrt{(\sigma_v^2 + \sigma_u^2)}$, $\lambda = \sigma_u/\sigma_v$, $\varepsilon_i = v_i - u_i = \ln y_i - X_i'\beta$, $\phi(\cdot)$ represents the standard normal density function, and $\Phi(\cdot)$ is the standard normal cumulative distribution function (Kumbhakar and Lovell 2000). Lastly, as the predicted values of u_i do not convey information regarding observed output relative to the optimal output, technical efficiency scores are derived from those predicted values:

$$TE_i = \frac{y_i}{\exp(X_i'\beta + v_i)} = \frac{\exp(X_i'\beta + v_i - u_i)}{\exp(X_i'\beta + v_i)} = \exp(-u_i). \quad (3.5)$$

The resulting measure of technical efficiency falls between zero and one, where one represents full efficiency (Coelli et al. 2005).

There have been numerous extensions to the basic stochastic frontier production function model throughout the years, but perhaps the most substantive development, at least with respect to this analysis, was the inclusion of exogenous determinants of technical inefficiency. On a basic level, models including these exogenous determinants have followed two (although not mutually exclusive) routes: (1) those assuming u distributed $N^+(\mu, \sigma_u^2)$ (i.e. truncated normal) and modeling μ as a function of some exogenous determinants or (2) those modeling σ_u^2 as a function of exogenous determinants (the latter not necessitating the truncated normal distribution). The choice of model, then, is driven by the data and, of course, the research question.

The first model, developed by Kumbhakar et al. (1991), Huang and Liu (1994), and Battese and Coelli (1995), while intuitively appealing, is not necessarily fitting for this analysis for three reasons. First, by nature of the research question, there is perceived heteroskedasticity in u as the observations in the sample differ substantially with respect

to land operated. As suggested by Caudill et al. (1995), “[t]he problem of heteroskedasticity is far more serious in frontier models because, unlike the mean regression function, the frontier *is* changed when the dispersion increases” (105), which can lead to biased parameter estimates. More importantly, heteroskedasticity affects the inefficiency measures, which can lead to the overestimation of inefficiency in small firms and the underestimation of inefficiency for large firms. Clearly, then, heteroskedasticity cannot be ignored. Second, the “mean” model does not possess the intuitively appealing “scaling property.” For example, $N^+(0, \sigma_{ui}^2(z_i, \gamma))$, which is the half-normal variance model incorporating exogenous factors (i.e. z_i), can be rewritten as $\sigma_{ui}(z_i, \gamma) \times N^+(0, 1)$. Above all, this suggests that the shape of the underlying distribution of u is the same for all firms, and the scaling factor, in this case $\sigma_{ui}(z_i, \gamma)$, merely stretches or shrinks the horizontal axis so that the scale of the distribution changes, whereas the underlying shape does not (see Wang and Schmidt [2002] for a complete discussion). Third, the mean model has proven to be extremely volatile (as is the case with this analysis), which is due to the weak identification of the parameter μ . Thus, the half-normal distribution appears quite attractive.

Given the above considerations, Caudill et al. (1995), building on Reifschneider and Stevenson (1991), proposed a model that serves as a logical starting point. On the basis of Eq. (3.3), the authors alternatively assumed $v_i \sim N(0, \sigma_v^2)$, $u_i \sim N^+(0, \sigma_{ui}^2)$, and $\sigma_{ui} = \exp(Z_i' \gamma)$. The specification remains largely identical to the originally proposed frontier models, but with one caveat: u_i is distributed half-normal with multiplicative heteroskedasticity in the variance, where Z_i is a $K \times 1$ vector of exogenous determinants of technical inefficiency for the i^{th} producer and γ is the parameter vector to be estimated.²⁶ The functional form of the variance term is easily constrained to yield the homoskedastic case as it readily incorporates an intercept.

Before turning to the empirical model it is necessary to briefly discuss another area of stochastic frontier analysis that has received a great deal of attention: panel models. While various models have been proposed throughout the years, one of the most well-received has

²⁶Positive values of coefficients in γ are interpreted as leading to increases in the estimated inefficiencies (Kumbhakar and Lovell 2000).

been the “true” random effects model developed in Greene (2005). The development of the “true” random effects model is crucial here for three primary reasons: (1) panel models previously in common use confounded unobserved heterogeneity with that of technical efficiency; (2) a “true” fixed effect estimator, in addition to being inconsistent as a result of the incidental parameters problem, would eliminate any time-invariant component of household-specific technical efficiency; and (3) the “true” random effects model, as a practical consideration, reduces computational burden as the “true” fixed effect model requires “brute force” estimation (Barrett et al. 2008; Greene 2005). Accordingly, consider the following:

$$\ln y_{it} = \alpha + X'_{it}\beta + w_i + v_{it} - u_{it} \quad (3.6)$$

where w_i is the random firm-specific effect, and v_{it} as well as u_{it} remain as discussed above. At first glance, identification appears an issue given the three-part disturbance. However, Greene argued that this is not the case, as the model actually has a two-part composed error and can be written as follows:

$$\ln y_{it} = (\alpha + w_i) + X'_{it}\beta + \varepsilon_{it} = \alpha_i + X'_{it}\beta + \varepsilon_{it}. \quad (3.7)$$

The above is an ordinary random effects model where the time-varying component has an asymmetric (non-normal) disturbance (w_i may, however, be normally distributed). As is common, in order to estimate the model via maximum likelihood, it is necessary to integrate the common term out of the likelihood function. As there is no closed form for the density of the compound disturbance, integration is done by quadrature or simulation. Further, the “true” random effects formulation is readily coupled with the variance model discussed above.

Moving to the empirical model, it is conventional to specify the production function as either Cobb-Douglas or translog. While the Cobb-Douglas is a simpler functional form, it does impose unitary elasticity of substitution. Moreover, with the translog being a more flexible functional form and merely a generalization of the Cobb-Douglas, it is less restrictive to begin with the translog specification and then conduct the relevant joint

hypothesis test for the nested Cobb-Douglas. Accordingly, the empirical model is as follows:

$$\begin{aligned} \ln y_{it} = & \alpha_i + \theta_1 d_{2001} + \theta_2 d_{2005} + \sum_{k=1}^K \beta_k \ln x_{kit} \\ & + \frac{1}{2} \sum_{k=1}^K \sum_{l=1}^L \beta_{kl} \ln x_{kit} \ln x_{lit} + \sum_{k=2}^K \tau_k d_{kit} + v_{it} - u_{it} \end{aligned} \quad (3.8)$$

where $v_{it} \sim N(0, \sigma_v^2)$, $u_{it} \sim N^+(0, \sigma_{uit}^2)$, and $\sigma_{uit}^2 = \exp(\delta + Z'_{it}\gamma)$. In the above, y_{it} represents the total value of output (as defined in Table 3.1) for the i^{th} producer at time t , d_{2001} and d_{2005} are dummy variables for the years 2001 and 2005, x_{kit} corresponds to the k^{th} production input (land operated, household labor days, hired labor days, and other variable inputs), and d_{kit} is a dummy variable that equals one when the k^{th} input takes a value of zero.

Before moving forward, the dummy variable approach to dealing with zero values of explanatory variables deserves elaboration. It is quite common, especially in developing countries, for producers not to utilize all inputs of the relevant production technology. Thus, with frequently observed zero values, some manipulation is required so as to take logarithmic transformations. While there are numerous approaches (e.g. scaling up by one or adding an arbitrarily small constant), Battese (1997), arguing that such methods can bias parameter estimates, developed a dummy variable approach that leads to consistent parameter estimates in the face of zero input values. The approach is simple: recode all zero values of explanatory variables to one and include a dummy variable for each input in the production function that takes on the value of one if that observation was recoded and zero otherwise.²⁷ Note that a dummy variable for land operated is not necessary, as this input never takes on a value of zero. All other inputs have zero values.

Referencing again Eq. (3.8), in the variance model, Z_{it} corresponds to a $K \times 1$ vector of technical inefficiency determinants: time dummies, land owned divided by land operated, land operated, male and female labor endowment, gender of the household head, age of the household head, the education of the household head, and the share of income from

²⁷For an application of the approach see Battese et al. (1996).

off-farm activities. When necessary, higher order polynomials are included to capture nonlinearities in land operated. As a final point, then, once a satisfactory model is specified and estimated, $E(u_{it}|\varepsilon_{it})$ and TE_{it} can be calculated.

3.4.3 Allocative Efficiency: Heckman Two-step

With the parameter estimates in hand from the production frontier, it is then possible to calculate allocative inefficiency, where, as described above, $AI_{it} = \ln(w_{it}/MRP_{Lit})$, which is simply the natural logarithm of the ratio of the observed median daily household wage for those households that participated in wage labor (which is 493, 561, and 1,081 households in 1998, 2001, and 2005, respectively) and the marginal revenue product of a day of on-farm household labor, where $MRP_L = \partial y / \partial L$ is calculated from the production frontier.²⁸ Note that the measure of AI is zero when $w = MRP_L$, negative when $w < MRP_L$ (signaling an under-application of labor), and positive when $w > MRP_L$ (signaling an over-application). Given the calculated AI , the objective is then to regress AI on a series of exogenous inefficiency determinants (including farm scale).

With respect to setting AI in a regression framework, it is necessary to account for sample selection bias so as to obtain consistent parameter estimates. Accordingly, the model is estimated with the Heckman two-step procedure as developed in Heckman (1979). Consider the following:²⁹

$$y_{1it}^* = X'_{1it}\beta_1 + u_{1it}, \quad (3.9)$$

$$y_{2it}^* = X'_{2it}\beta_2 + u_{2it}, \quad (3.10)$$

$$y_{1it} = y_{1it}^* \text{ if } y_{2it}^* > 0, \quad (3.11)$$

$$y_{1it} = 0 \text{ if } y_{2it}^* \leq 0. \quad (3.12)$$

²⁸Technically speaking, measurement of household labor in days renders it a discrete variable. Accordingly, the marginal revenue product is calculated as the difference between predicted revenue at observed inputs and the predicted revenue when days of household labor is scaled up by one.

²⁹For the sake of brevity, the following exposition of Heckman's model adheres to that which is developed in Puhani (2000).

In the above, Eq. (3.9) is the model of primary interest and Eq. (3.10), in this case, is a probit-type selection equation that describes the selection mechanism (e.g. participation in wage employment). The variables y_1^* and y_2^* are unobserved, whereas y_1 is observed. It is most commonly assumed that u_1 and u_2 follow a bivariate normal distribution:

$$\begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \sim BN \left[\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_1^2 & \sigma_{12} \\ \sigma_{12} & \sigma_2^2 \end{bmatrix} \right]. \quad (3.13)$$

For those households with a positive y_1^* (i.e. an observed wage), the conditional expectation of y_1^* is

$$E(y_{1it}^* | X_{1it}, y_{2it}^* > 0) = X'_{1it}\beta_1 + E(u_{1it} | u_{2it} > -X'_{2it}\beta_2) \quad (3.14)$$

where, given the distribution of u_1 and u_2 , the conditional expectation of the error term is

$$E(u_{1it} | u_{2it} > -X'_{2it}\beta_2) = \frac{\sigma_{12}}{\sigma_2} \frac{\phi(-(X'_{2it}\beta_2/\sigma_2))}{1 - \Phi(-(X'_{2it}\beta_2/\sigma_2))} \quad (3.15)$$

where $\phi(\cdot)$ and $\Phi(\cdot)$ represent the density and cumulative density functions of the standard normal distribution. The inverse Mills ratio can then be defined as follows:

$$\lambda_{it}(X'_{2it}\beta_2/\sigma_2) = \frac{\phi(-(X'_{2it}\beta_2/\sigma_2))}{1 - \Phi(-(X'_{2it}\beta_2/\sigma_2))}. \quad (3.16)$$

Accordingly, when including Eq. (3.16), Eq. (3.9) can be estimated consistently with OLS. That is, estimation is consistent when

$$y_{1it} = X'_{1it}\beta_1 + \frac{\sigma_{12}}{\sigma_2} \lambda_{it}(X'_{2it}\beta_2/\sigma_2) + \varepsilon_{1it} \quad (3.17)$$

or simply

$$y_{1it} = X'_{1it}\beta_1 + \theta \lambda_{it} + \varepsilon_{1it}. \quad (3.18)$$

In short, the first step is to use a probit model to estimate Eq. (3.10) and then for each observation calculate the inverse Mills ratio using the probit coefficients. Then, in the second step, linearly regress y_{1it} on X_{1it} and λ_{it} to estimate β_1 and θ . It is important to

note here, however, that it is necessary to adjust the standard errors and the estimate of σ_ε^2 , which are inconsistent (see Heckman [1979] or Greene [1981] for the specific calculations).

A large body of literature has developed regarding specification issues in the Heckman two-step procedure. As, theoretically, it is frequently desirable to include the same variables in the probit and primary models, the researcher runs the risk of introducing excessive multicollinearity in the primary model via the inverse Mills ratio, as the inverse Mills ratio is an approximately linear function over a wide range of its argument. As such, the present analysis uses two methods in an attempt to avoid or mitigate these issues: (1) exclusion restrictions and (2) condition numbers. Regarding exclusion restrictions, Rendtel (1992) showed that the performance of the Heckman model can be greatly improved if the researcher includes variables in X_2 and not X_1 that are correlated with y_2 and not y_1 . Deaton (1997) contended that at least one of these variables must be continuous for satisfactory identification. Accordingly, we include the prevailing municipality wage, distance to nearest health center, and agricultural/livestock assets in the probit model, all of which satisfy the above criteria. Further, as exclusion restrictions in and of themselves do not guarantee satisfactory identification, condition numbers have been monitored throughout the modeling process so as to avoid multicollinearity issues (see Leung and Yu [1996] for a thorough discussion of condition numbers in the Heckman two-step). The only constraint this has imposed has been regarding the inclusion of higher order polynomials in the primary model, as this leads to an untenable increase in the condition number.

Once a satisfactory model has been specified, the parameters can then be used to impute allocative inefficiency for those households that did not participate in wage labor, as

$$\hat{A}I_{it} = \hat{y}_{1it} = X'_{1it}\beta_1 + \theta\lambda_{it}. \quad (3.19)$$

Given estimates of allocative inefficiency for all households, it is beneficial to transform those estimates in order to facilitate interpretation. Analogous to the case of technical efficiency, we require a transformation that yields the value of one when $AI = 0$ and approaches zero as AI deviates from zero. The kernel of the normal density function readily

provides such properties. Consider the following expression for allocative *efficiency*:

$$AE_{it} = \exp \left(-\frac{AI_{it}^2}{2\sigma_{AI}^2} \right) \quad (3.20)$$

where μ has been set to zero (as this represents perfect allocative efficiency) and σ_{AI}^2 is the observed variance of AI as calculated around a mean of zero.³⁰ It is clear, then, that when $AI = 0$ the resulting value of AE is one.

A few further comments should be made regarding this step in the analysis. First, in Eq. (3.10) (i.e. the probit model), a dummy variable for participation in wage labor (participation equals one) is regressed on a series of managerial and household characteristics, including: year dummies, prevailing wage in the household's municipality,³¹ distance to the nearest health center (as a proxy for proximity to employment opportunities), quantity of land owned, value of agricultural/livestock assets, ethnicity (i.e. Indigenous), gender of the household head, marriage status of the household head, age of the household head, education of the household head, number of male and female laborers, and number of government programs from which the household benefits. The variables in Eq. (3.9) (i.e. the primary model) are precisely those in the variance equation of the production frontier plus the inverse Mills ratio. Second, the Heckman two-step is estimated in a pooled manner as the quantity of unobserved wage data renders a panel specification unfeasible. Finally, following Barrett et al. (2008), as a result of the estimated nature of AI , standard errors of the primary equation are bootstrapped with 1,000 replications.

3.4.4 Market Imperfections Framework Revisited

Regarding the final stage, we revisit the market imperfections framework, a revisitation motivated by way of omitted variable bias. Following Greene (2008), consider the

³⁰While it is possible to calculate the variance of AI on its own mean, when the marginal revenue product of labor deviates in a structural manner from the observed wage (i.e. the distribution of AI is not centered on zero), calculating the variance in this manner will yield estimates of AE that lack economic meaning.

³¹This is simply the median wage for each municipality in a given year. The median wage is calculated from the observed wages in the sample. There are 153 municipalities in Nicaragua.

following correctly specified regression:

$$\mathbf{y} = \mathbf{X}_1\beta_1 + \mathbf{X}_2\beta_2 + \varepsilon \quad (3.21)$$

where $\mathbf{y}$ is a $NT \times 1$ vector for observations $i = 1, 2, \dots, N$ at times $t = 1, 2, \dots, T$, $\mathbf{X}_j$ is a $NT \times K_j$ matrix for $j = 1, 2$, β_j is a $K_j \times 1$ vector of parameters, and ε is a $NT \times 1$ vector of disturbances. Further, let $\mathbf{y}$ and $\mathbf{X}_1$ embody the specification elaborated upon in Section 3.4.1 and let $\mathbf{X}_2$ contain the time-varying technical and allocative efficiency estimates discussed in Sections 3.4.2 and 3.4.3. Regressing $\mathbf{y}$ on $\mathbf{X}_1$ without the inclusion of $\mathbf{X}_2$ yields the following estimator:

$$\mathbf{b}_1 = (\mathbf{X}_1'\mathbf{X}_1)^{-1} \mathbf{X}_1'\mathbf{y} = \beta_1 + (\mathbf{X}_1'\mathbf{X}_1)^{-1} \mathbf{X}_1'\mathbf{X}_2\beta_2 + (\mathbf{X}_1'\mathbf{X}_1)^{-1} \mathbf{X}_1'\varepsilon. \quad (3.22)$$

Taking the expectation then, we have:

$$E[\mathbf{b}_1|\mathbf{X}] = \beta_1 + (\mathbf{X}_1'\mathbf{X}_1)^{-1} \mathbf{X}_1'\mathbf{X}_2\beta_2 \quad (3.23)$$

where unless $\mathbf{X}_1'\mathbf{X}_2 = \mathbf{0}$ or $\beta_2 = \mathbf{0}$ it is evident that $\mathbf{b}_1$ is biased. It follows immediately from the discussion in Section 3.2 that *a priori* we cannot assume $\mathbf{X}_1'\mathbf{X}_2 = \mathbf{0}$ or $\beta_2 = \mathbf{0}$. Thus, in this final stage we include the estimates of technical and allocative efficiency in the market imperfections framework so as to examine the direction and magnitude of the omitted variable bias. Lastly, due to the estimated nature of technical and allocative efficiency, the standard errors are bootstrapped with 1,000 replications.

3.5 Results

3.5.1 Market Imperfections Framework

Tables 3.3-3.5 display the results from the initial estimation of the market imperfections models for the samples of all, beans and maize, and diversified producers, respectively.³² Note that each table presents the results for each of the three aforementioned

³²All estimation and subsequent calculations were conducted in LIMDEP 9.0.

dependent variables. Given that this stage of the analysis is largely motivational, here we confine our attention to the coefficient estimates associated with operational landholdings. For each regression in each table, the robust statistical significance of the higher-order terms suggests that a cubic specification is most appropriate.³³ Further, the coefficients on all first-, second-, and third-order terms are negative, positive, and negative, respectively, thereby suggesting similar non-linear relationships across specifications. Interestingly, the two inflection points implied by the parameter estimates are quite similar across regressions *within* each sample of producers. For the samples of all, beans and maize, and diversified producers, the first (second) inflection point occurs at approximately 53 (137), 45 (128), and 57 (141) *manzanas*, respectively.³⁴ In each of these samples, 94, 95, and 92 percent of producers, respectively, operate landholdings below that of the first inflection point, which suggests that an inverse relationship is operative for the vast majority of producers in each sample. That is, given less statistical uncertainty and outlier sensitivity associated with the downward-sloping portion of the relationship, it appears that not only is there persuasive evidence, across all samples, that smaller-scale producers display higher levels of output and farm value added per unit of land operated, but the likely explanation for these findings is the greater application of labor per unit of land operated. With relatively high R^2 values for each regression in each table, it is evident that the market imperfections framework conforms with the data reasonably well, but the question remains as to whether the specification suffers from omitted variable bias. As such, we turn to the estimation of technical and allocative efficiency.

3.5.2 Technical Efficiency: Stochastic Frontier Analysis

Tables 3.6-3.9 and Figures 3.3-3.5 present the results of the technical efficiency analysis. To start, consider jointly Tables 3.6 and 3.7. Table 3.6 displays the results of the

³³Note the division of the second- and third-order terms by 100 and 1000, respectively. The transformation, by shifting the decimal place in the parameter estimates, merely facilitates the presentation of the results. Any subsequent calculations, however, necessarily take into account the transformed data. Such transformations are used throughout the analysis, but in no way affect the final results.

³⁴Inflection points for the market imperfections models are calculated from the parameter estimates of a least squares regression of the predicted values from the relevant regression on a third-order polynomial of land operated.

Table 3.3: Fixed Effects Model (All)

Variable	Land Productivity		Value Added		Labor Usage	
	Coeff.	SE	Coeff.	SE	Coeff.	SE
d_{2001}	1,074.58***	207.35	826.18***	115.28	14.71	9.11
d_{2005}	613.86***	218.81	974.34***	121.65	92.41***	9.62
Owned/Operated	6.11	35.57	13.19	19.77	0.10	1.56
Operated	-203.29***	23.87	-160.87***	13.27	-12.54***	1.05
Operated ² /100	265.29***	43.55	203.80***	24.21	16.99***	1.91
Operated ³ /1000	-9.41***	1.93	-7.04***	1.08	-0.60***	0.09
Male Labor	-3.68	104.59	15.06	58.15	2.60	4.60
Female Labor	-10.09	119.39	29.86	66.38	2.19	5.25
Share	-10.00***	3.10	-13.23***	1.73	-0.04	0.14
R^2	0.59		0.70		0.79	
N	5,743		5,743		5,743	

* P-values <0.01, 0.05, and 0.10 correspond to ***, **, and *, respectively.

Table 3.4: Fixed Effects Model (Beans and Maize)

Variable	Land Productivity		Value Added		Labor Usage	
	Coeff.	SE	Coeff.	SE	Coeff.	SE
d_{2001}	631.88***	161.33	770.91***	152.09	2.85	13.10
d_{2005}	1,194.28***	154.21	1,298.48***	145.37	109.86***	12.52
Owned/Operated	-29.56	32.82	-4.13	30.94	-0.01	2.67
Operated	-319.60***	30.98	-269.87***	29.21	-22.82***	2.52
Operated ² /100	652.86***	83.31	556.09***	78.54	46.91***	6.77
Operated ³ /1000	-34.56***	5.09	-29.54***	4.80	-2.46***	0.41
Male Labor	84.96	77.45	5.35	73.02	-4.66	6.29
Female Labor	-63.30	86.08	-68.56	81.15	-1.63	6.99
Share	-11.54***	2.23	-11.67***	2.10	-0.11	0.18
R^2	0.91		0.93		0.96	
N	2,596		2,596		2,596	

* P-values <0.01, 0.05, and 0.10 correspond to ***, **, and *, respectively.

random effect production frontier for all (All), beans and maize (BM), and diversified (D) producers. To understand the coefficient estimates, however, it is beneficial to focus on Table 3.7, which provides a series of relevant Wald tests. First, Wald test (1) examines the joint significance of the translog terms (i.e. all quadratic and interaction terms). For each sample, we reject the null hypothesis of a nested Cobb-Douglas production technology at any conventional level of significance. Second, hypothesis tests (2)-(5) present an

Table 3.5: Fixed Effects Model (Diversified)

	Land Productivity		Value Added		Labor Usage	
Variable	Coeff.	SE	Coeff.	SE	Coeff.	SE
d_{2001}	962.94***	273.86	588.59***	132.26	2.91	9.85
d_{2005}	290.22	330.99	671.93***	159.86	61.83***	11.90
Owned/Operated	38.60	52.74	33.35	25.47	-0.46	1.90
Operated	-156.68***	30.57	-140.89***	14.76	-9.54***	1.10
Operated ² /100	184.80***	51.41	166.90***	24.83	12.04***	1.85
Operated ³ /1000	-6.12***	2.18	-5.45***	1.05	-0.41***	0.08
Male Labor	-96.41	156.91	-72.15	75.78	-7.83	5.64
Female Labor	44.61	187.33	67.14	90.47	2.80	6.73
Share	-1.59	4.53	-7.14***	2.19	0.06	0.16
R^2	0.82		0.86		0.86	
N	3,147		3,147		3,147	

* P-values <0.01, 0.05, and 0.10 correspond to ***, **, and *, respectively.

estimate, for each sample, of the mean output elasticity for each input in addition to the test of statistical significance.³⁵ It is evident that all output elasticities for each sample are positive and statistically significant, frequently at the 1 percent level. Finally, Wald test (6) displays the estimated elasticity of scale for each sample,³⁶ which is not significantly different from unity for the sample of all producers as well as the sample of beans and maize producers. However, for the diversified producers, we reject the null hypothesis of constant returns to scale at the 5 percent level. Thus, with the exception of the diversified producers, the findings here are consistent with those of Abdulai and Eberlin (2001), as discussed above.

Of primary interest is the technical inefficiency model in Table 3.8, especially those results that pertain to operational landholdings. Regarding the sample of all producers, the

³⁵The output elasticity of the k^{th} input $\varepsilon_k = \partial \ln y / \partial \ln x_k = \beta_k + \sum_{j=1}^K \beta_{kj} \ln x_j$. Also, note the distinction between the elasticities evaluated at the mean and the mean elasticities. Given the skewed distribution of some inputs (e.g. operational landholdings), calculating each elasticity at the input level for each producer and then taking the mean of these elasticities is preferable as the resulting distributions of the elasticities are approximately normal.

³⁶The scale elasticity is simply equal to the sum of the output elasticities for each input. The production function exhibits locally decreasing, constant, or increasing returns to scale when the elasticity of scale is less than, equal to, or greater than unity.

Table 3.6: Random Effect Production Frontier

	All		BM		D	
Variable	Coeff.	SE	Coeff.	SE	Coeff.	SE
d_{2001}	0.3870***	0.0378	0.3575***	0.0521	0.3307***	0.0453
d_{2005}	0.2737***	0.0340	0.2128***	0.0414	0.4375***	0.0460
$\ln X_1$	0.3542***	0.0541	0.3227***	0.0566	0.2923***	0.0698
$\ln X_2$	0.1247	0.0849	-0.1048	0.1156	0.1214	0.1076
$\ln X_3$	0.3303***	0.0705	0.2697***	0.0918	0.3155***	0.1000
$\ln X_4$	0.6234***	0.0877	0.5625***	0.1176	0.6003***	0.1187
$\frac{1}{2} \ln(X_1)^2$	0.0117**	0.0057	-0.0563***	0.0105	0.0096	0.0077
$\ln X_1 \times \ln X_2$	-0.0199**	0.0090	-0.0042	0.0116	-0.0173	0.0114
$\ln X_1 \times \ln X_3$	-0.0162***	0.0039	-0.0185***	0.0063	-0.0153***	0.0051
$\ln X_1 \times \ln X_4$	0.0167**	0.0080	0.0159	0.0110	0.0057	0.0104
$\frac{1}{2} \ln(X_2)^2$	0.0211	0.0158	0.0539**	0.0213	0.0193	0.0199
$\ln X_2 \times \ln X_3$	-0.0072	0.0073	0.0129	0.0093	-0.0143	0.0103
$\ln X_2 \times \ln X_4$	-0.0603***	0.0135	-0.0686***	0.0181	-0.0405**	0.0183
$\frac{1}{2} \ln(X_3)^2$	-0.0341**	0.0148	-0.0632***	0.0194	-0.0174	0.0210
$\ln X_3 \times \ln X_4$	-0.0263***	0.0054	-0.0127*	0.0068	-0.0316***	0.0072
$\frac{1}{2} \ln(X_4)^2$	-0.0460*	0.0270	-0.0444	0.0332	-0.0726*	0.0371
d_2	0.3489	0.3822	0.5552	0.4998	0.2458	0.5293
d_3	0.3432***	0.1177	0.5062***	0.1456	0.1816	0.1721
d_4	-0.0621	0.0426	-0.1465***	0.0477	0.0073	0.0604
N	5,743		2,596		3,147	

* P-values <0.01, 0.05, and 0.10 correspond to ***, **, and *, respectively.

** The subscripts 1, 2, 3, and 4 refer to land operated, household labor, hired labor, and other variable inputs, respectively.

Table 3.7: Wald Tests

	All		BM		D	
Hypothesis	Est.	Test Stat.	Est.	Test Stat.	Est.	Test Stat.
(1) $\beta_{11} = \beta_{12} = \dots = \beta_{44} = 0$	-	123.98***	-	146.63***	-	82.55***
(2) $\varepsilon_1 = 0$	0.2757	320.10***	0.1453	63.11***	0.2136	97.98***
(3) $\varepsilon_2 = 0$	0.2606	6.40**	0.4710	11.45***	0.2418	3.45*
(4) $\varepsilon_3 = 0$	0.1493	29.39***	0.1842	19.63***	0.1156	11.48***
(5) $\varepsilon_4 = 0$	0.1545	45.06***	0.0717	9.36***	0.1399	13.14***
(6) $\sum \varepsilon_k = 1$	0.8401	2.09	0.8723	0.79	0.7108	4.16**

* P-values <0.01, 0.05, and 0.10 correspond to ***, **, and *, respectively.

** The subscripts 1, 2, 3, and 4 refer to land operated, household labor, hired labor, and other variable inputs, respectively.

Table 3.8: Technical Inefficiency Model

	All		BM		D	
Variable	Coeff.	SE	Coeff.	SE	Coeff.	SE
Intercept	0.2103***	0.0757	0.6268***	0.1086	0.4860***	0.0953
d_{2001}	-0.1754***	0.0369	-0.0231	0.0708	-0.2941***	0.0420
d_{2005}	-0.2126***	0.0323	-0.1982***	0.0534	-0.1692***	0.0383
Owned/Operated	-0.0163***	0.0053	-0.0153*	0.0089	-0.0182***	0.0056
Operated	0.0106***	0.0022	0.0030**	0.0014	-0.0032**	0.0014
Operated ² /100	-0.0128***	0.0037	-	-	0.0028***	0.0009
Operated ³ /1000	0.0005***	0.0002	-	-	-	-
Male Labor	-0.0508***	0.0100	-0.0497***	0.0138	-0.0476***	0.0132
Female Labor	-0.0071	0.0125	-0.0025	0.0176	-0.0065	0.0162
Female	0.0315	0.0250	-0.0162	0.0410	0.0411	0.0333
Age	0.0035***	0.0007	0.0007	0.0010	0.0051***	0.0009
Education	0.0075**	0.0031	-0.0013	0.0046	0.0112***	0.0043
Share	0.0085***	0.0003	0.0072***	0.0005	0.0086***	0.0004
N	5,743		2,596		3,147	

* P-values <0.01, 0.05, and 0.10 correspond to ***, **, and *, respectively.

statistical significance of the higher-order terms of operational landholdings suggests that a cubic specification is fitting. Accordingly, there are two inflection points, which occur at approximately 71 and 100 *manzanas*. That is, technical inefficiency is estimated to increase in operational landholdings up to 71 *manzanas*, decrease from 71 to 100 *manzanas*, and then increase again thereafter. Crucially, 96 percent of the sample operates landholdings less than 71 *manzanas*, which suggests that an inverse relationship between operational landholdings and technical *efficiency* is effective for the overwhelming majority of producers. With respect to beans and maize producers, as a linear specification appears most appropriate, it is clear from the positive and statistically significant coefficient on land operated that the finding of an inverse relationship persists with this subsample of producers. Conversely, turning to the diversified producers, where we employ a quadratic specification, the parameter estimates suggest a statistically significant, negative, and convex relationship in technical inefficiency. With a minimum being reached at approximately 57 *manzanas* and 92 percent of producers in this subsample operating landholding less than this minimum, it is evident that a direct relationship between operational landholdings and

technical *efficiency* is operative for the vast majority of this sample. Thus, the estimated inverse relationship for the entire sample appears to be driven by the sample of beans and maize producers.

Some other interesting conclusions emerge from Table 3.8 as well. First, the ratio of owned to operated landholdings is negative and statistically significant for all samples, which suggests that increasing ownership landholdings may indeed improve technical efficiency via credit constraint relaxation (Binswanger et al. 1995). Second, technical inefficiency is significantly decreasing in household male labor endowments for all samples, which is in accordance with accepted theory on moral hazard associated with hired labor in developing country agriculture (as, all else equal, lesser endowments of household labor require greater quantities of hired labor to meet production targets). There appears, however, a certain asymmetry between male and female labor, as the coefficient on female labor is not statistically significant in any sample. Finally, technical inefficiency is significantly increasing in the age and education of the household head (for the samples of all and diversified producers) as well as the household share of income from off-farm activities (for all samples).

As a final consideration, descriptive statistics and kernel density estimates of the technical efficiency scores are provided in Table 3.9 and Figures 3.3-3.5. Regarding Table 3.9, for all samples and all years, mean technical efficiency hovers around 60 percent, which is largely in accordance with other empirical studies of Latin American agricultural and livestock production.³⁷ Further, while bean and maize producers tend to witness higher average technical efficiency scores, there does not appear to be any definitive trends in the scores across time. Lastly, Figures 3.3-3.5 illustrate that in all cases the distributions of the TE scores are slightly skewed with modes at approximately 70 percent. Thus, even though the depictions of the entire distributions illustrate that the majority of the producers witness TE scores above that of the sample means, there still appears to be considerable room for improvement in technical efficiency.

³⁷See Bravo-Ureta and Pinheiro (1993) for a review of technical efficiency estimates in developing country agriculture. Further, see Bravo-Ureta and Evenson (1994) for an example of an empirical study of Latin American agriculture that observes technical efficiency estimates in the vicinity of 60 percent.

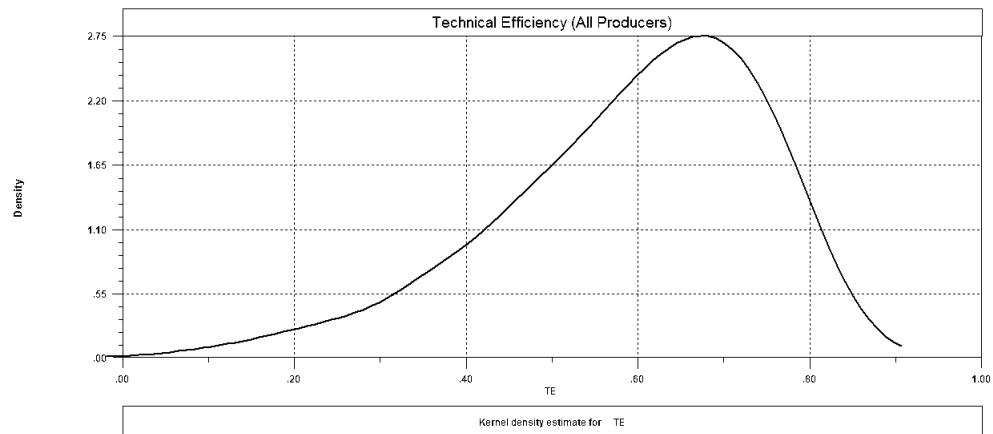


Figure 3.3: Kernel Density Estimates of TE Scores (All Producers)

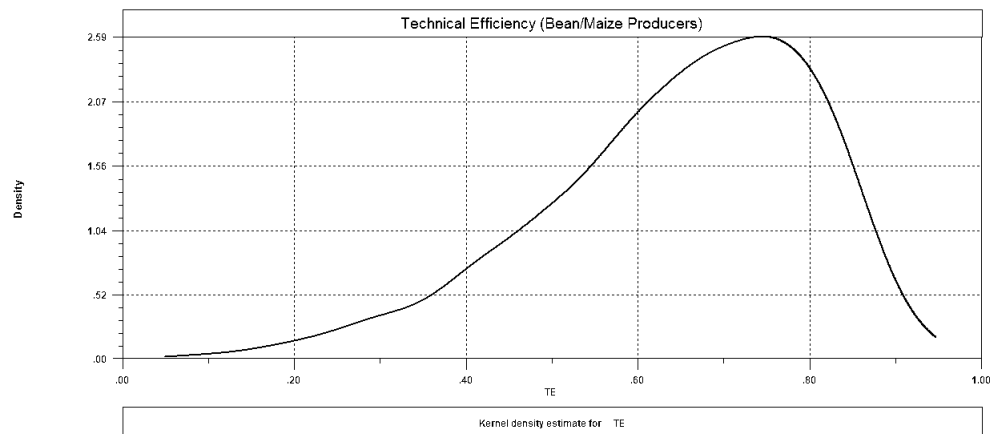


Figure 3.4: Kernel Density Estimates of TE Scores (Beans and Maize Producers)

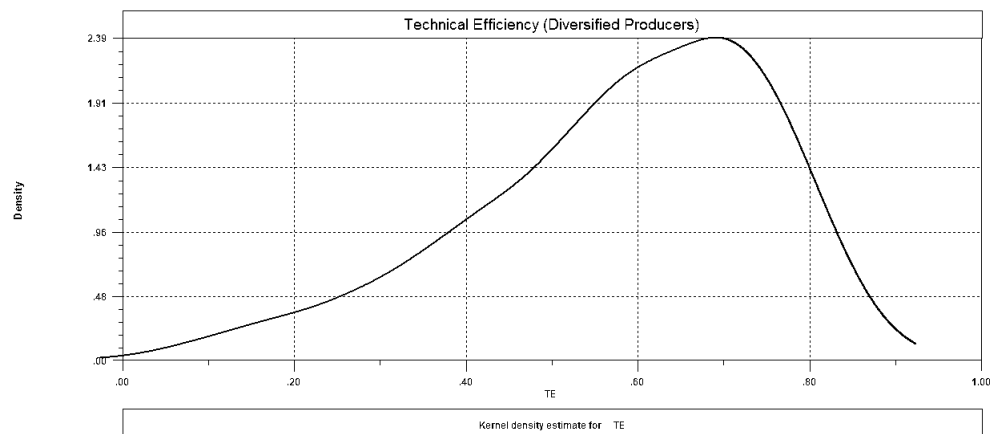


Figure 3.5: Kernel Density Estimates of TE Scores (Diversified Producers)

Table 3.9: Technical Efficiency Estimates by Year

	1998		2001		2005		Overall	
Sample	Mean	SD	Mean	SD	Mean	SD	Mean	SD
All	0.5795	0.1611	0.5922	0.1541	0.5979	0.1493	0.5920	0.1536
BM	0.6371	0.1611	0.6246	0.1682	0.6579	0.1459	0.6475	0.1539
D	0.5624	0.1780	0.5942	0.1624	0.5785	0.1743	0.5793	0.1719

3.5.3 Allocative Efficiency: Heckman Two-step

As discussed, before estimation of the Heckman two-step, it is necessary to calculate $AI_{it} = \ln(w_{it}/MRP_{Lit})$ for the subsample of households that participated in wage labor. While the daily wage is observed, the marginal revenue product of labor must be calculated using the parameters from the production frontier, where $MRP_L = \partial y / \partial L$, which is evaluated at the observed input levels of each producer. It is common in these calculations, as is the case here, to find negative values for MRP_L (for examples see Jacoby [1993] or Skoufias [1994]). While there are numerous possible ways to treat the issue, in an effort to limit introducing undue bias into subsequent estimation, these observations are simply omitted from the analysis. The negative values, however, are only witnessed for approximately 7, 3, and 6 percent of the samples of all, beans and maize, and diversified producers, respectively, so the loss of observations, while unwelcome, is minimal. For the remaining observations, Table 3.10 presents descriptive statistics for the resulting AI estimates by year and sample. In examining the descriptive statistics, it is evident that, for all years and all samples, mean AI lies above zero (i.e. perfect allocative efficiency), which suggests that, on average, Nicaraguan households over-applied labor to agricultural and livestock production. Moreover, across time, there does not appear to be any discernible trend toward improved allocative efficiency for any of the samples. While adequate explanation of this phenomenon is beyond the scope of this analysis, it is quite likely that labor market imperfections and/or transaction costs explain at least some of the deviation from the optimal allocation of labor (see Malchow-Møller and Svarer [2005] for a complete discussion).

Table 3.10: Allocative Inefficiency Estimates by Year

	1998		2001		2005		Overall	
Sample	Mean	SD	Mean	SD	Mean	SD	Mean	SD
All	8.7567	0.9957	8.6656	0.9624	9.1893	0.9127	8.9525	0.9755
BM	9.3618	0.8036	9.3249	0.7838	9.7987	0.8301	9.6373	0.8453
D	1.4764	1.0699	1.4229	0.9673	1.7376	0.8897	1.5582	0.9775

Moving forward, Tables 3.11 and 3.12 display the results from the probit and primary models for the Heckman two-step procedure where the dependent variable of the probit model is participation in wage labor and the dependent variable of the sample selection model is allocative inefficiency. With respect to the probit model, it is evident that the signs on all coefficients are in accordance with theory. For the majority, if not all, of samples, the prevailing municipality wage as well as proximity to employment opportunities (as proxied by distance to nearest health center) are both factors that appear to exert a statistically significant “pulling” influence on household labor, whereas a lack of land owned and/or productive assets can be viewed as “push” factors that induce wage labor participation. Further, regarding demographic characteristics, indigenous households and households with married heads display a significantly negative relationship with wage labor participation whereas older and more educated households as well as households with greater (male and female) labor endowments are significantly more likely to participate in wage labor. Finally, benefitting from government programs significantly enhances the likelihood of wage labor participation in all samples.

Moving to the primary model, it can be seen from Table 3.12 that land operated is only statistically significant for the sample of diversified producers, albeit at the 10 percent level. The positive coefficient here implies that larger producers are more allocatively inefficient than that of their smaller counterparts, a finding which contrasts with that of the aforementioned direct relationship between operational landholdings and technical efficiency for this sample of producers. With respect to other findings, regarding demographic characteristics, it is evident that, at least for the samples of all and diversified producers, households with more male laborers, older household heads, and/or household heads with

Table 3.11: Probit Model

Variable	All		BM		D	
	Coeff.	SE	Coeff.	SE	Coeff.	SE
Intercept	-0.7912***	0.0984	-0.8595***	0.1428	-0.6801***	0.1356
d_{2001}	0.0412	0.0539	0.0360	0.0882	0.0074	0.0683
d_{2005}	0.0698	0.0491	0.0977	0.0736	0.0233	0.0684
Municipality Wage	0.0056***	0.0022	0.0095***	0.0031	0.0021	0.0030
Distance to Health Center	-0.0125***	0.0027	-0.0129***	0.0045	-0.0124***	0.0033
Owned	-0.0108***	0.0015	-0.0193***	0.0028	-0.0085***	0.0017
Owned ² /100	0.0050***	0.0008	0.0109***	0.0018	0.0034***	0.0009
Assets	-0.0076***	0.0014	-0.0080***	0.0030	-0.0069***	0.0016
Indigenous	-0.4539***	0.0868	-0.0969	0.1623	-0.5755***	0.1041
Female	-0.0762	0.0515	-0.0853	0.0742	-0.0466	0.0707
Married	-0.1345***	0.0395	-0.1204**	0.0578	-0.1515***	0.0533
Age	0.0025**	0.0012	0.0032*	0.0018	0.0016	0.0017
Education	0.0176***	0.0053	0.0102	0.0077	0.0207***	0.0072
Male Labor	0.0987***	0.0177	0.0700***	0.0254	0.1304***	0.0245
Female Labor	0.0996***	0.0193	0.0737***	0.0284	0.1186***	0.0261
Government Programs	0.0632***	0.0140	0.0638***	0.0206	0.0670***	0.0188
Pseudo R^2	0.05		0.05		0.06	
N	5,331		2,521		2,943	

* P-values <0.01, 0.05, and 0.10 correspond to ***, **, and *, respectively.

greater education levels tend to be significantly more allocatively inefficient. The only truly unexpected result here is the parameter estimates on education, but the exploration of the explanation is beyond the scope of the present analysis. Further, the share of income from off-farm activities is positive and statistically significant for each sample, which implies that those households less dependent on agricultural and livestock production witness greater allocative inefficiency. Lastly, while the insignificance of λ for each sample suggests that selection bias is not of immediate concern, for the sake of theoretical integrity, we maintain the two-step specification.

With the estimates from the Heckman two-step, it is then possible to impute AI for *all* observations and apply the above-discussed allocative efficiency transformation. Descriptive statistics and kernel density estimates are presented in Table 3.13 and Figures 3.6-3.8, respectively. Looking toward the descriptive statistics, mean allocative efficiency consistently hovers around 60 percent, with the only exception being those estimates for

Table 3.12: Primary Model

Variable	All		BM		D	
	Coeff.	SE	Coeff.	SE	Coeff.	SE
Intercept	8.0793***	0.2829	9.4342***	0.3728	0.4703	0.3224
d_{2001}	-0.0896	0.0640	-0.0813	0.0901	-0.0440	0.0796
d_{2005}	0.4292***	0.0597	0.3631***	0.0809	0.2607***	0.0842
Owned/Operated	0.0071	0.0076	0.0076	0.0165	0.0013	0.0166
Operated	0.0019	0.0019	-0.0018	0.0037	0.0038*	0.0022
Male Labor	0.0726***	0.0238	0.0121	0.0280	0.1046***	0.0332
Female Labor	0.0039	0.0257	-0.0361	0.0336	0.0246	0.0349
Female	0.0080	0.0612	0.1317*	0.0731	-0.0794	0.0900
Age	0.0028**	0.0014	0.0009	0.0019	0.0035*	0.0020
Education	0.0218***	0.0065	0.0038	0.0087	0.0389***	0.0102
Share	0.0026***	0.0010	0.0031***	0.0012	0.0035***	0.0013
λ	0.1469	0.1931	-0.3237	0.2588	0.2262	0.2183
R^2	0.08		0.09		0.07	
N	2,008		984		1,055	

* P-values <0.01, 0.05, and 0.10 correspond to ***, **, and *, respectively.

** Standard errors are bootstrapped with 1,000 replications.

diversified producers for the years 1998 and 2001, which are approximately 70 percent. Importantly, the data suggests that allocative efficiency declined for all samples of producers from 1998 to 2005, a deterioration that reaches approximately 10 percent for the sample of diversified producers. Moreover, regarding Figures 3.6-3.8, there appears substantial variation in the estimates as, across samples, they cover a wide range of values, with minimum values nearing zero and maximum values approaching one. Accordingly, these estimates point toward non-negligible resource allocation issues in Nicaraguan agricultural/livestock production.

Table 3.13: Allocative Efficiency Estimates by Year

Sample	1998		2001		2005		Overall	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
All	0.6227	0.0415	0.6275	0.0415	0.5912	0.0394	0.6082	0.0439
BM	0.6224	0.0307	0.6258	0.0321	0.5971	0.0348	0.6076	0.0360
D	0.7028	0.2117	0.7154	0.2070	0.6078	0.1928	0.6681	0.2087



Figure 3.6: Kernel Density Estimates of AE Scores (All Producers)

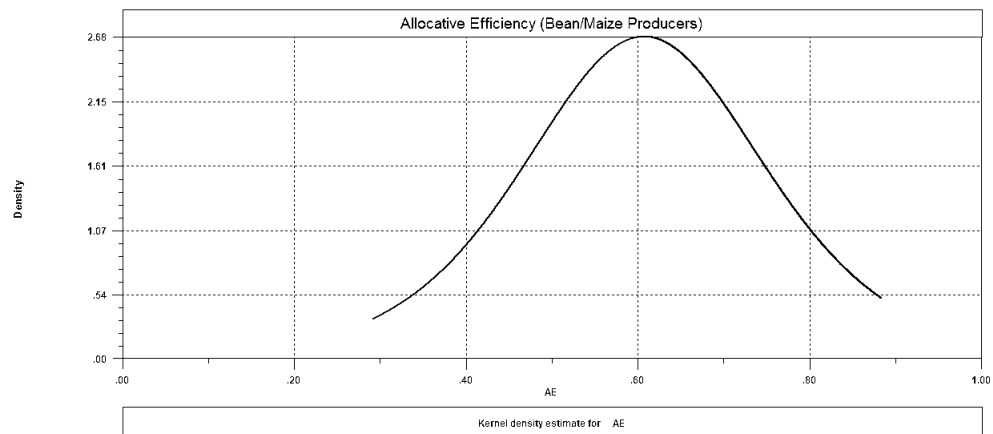


Figure 3.7: Kernel Density Estimates of AE Scores (Beans and Maize Producers)

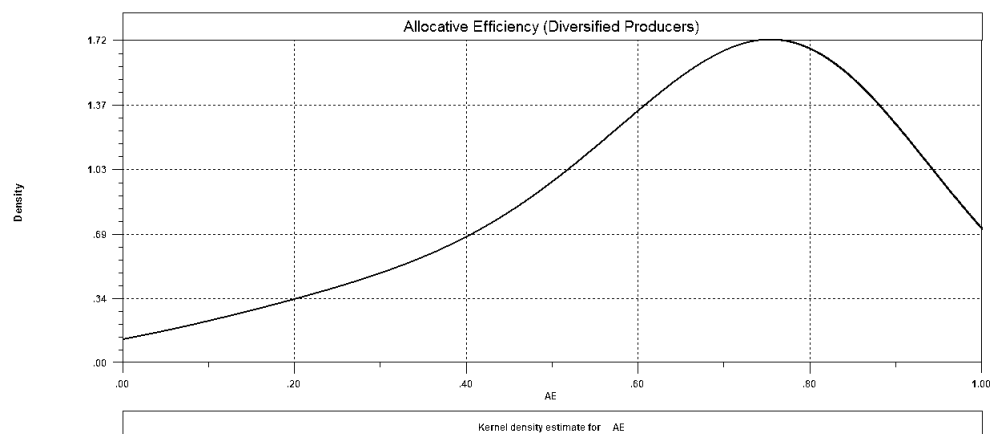


Figure 3.8: Kernel Density Estimates of AE Scores (Diversified Producers)

3.5.4 Market Imperfections Framework Revisited

Tables 3.14-3.16 and Figures 3.9-3.11 present the revisited market imperfections models, which now include as regressors the estimates of technical and allocative efficiency. With respect to Table 3.14 and the sample of all producers, it is evident that the coefficients on technical efficiency are positive and highly statistically significant for the land productivity and farm value added models. Theoretically, such parameter estimates are to be expected given that, all else equal, enhanced technical efficiency increases output/revenue, which in turn exerts a positive influence on the dependent variables. Conversely, for all models, the coefficients on allocative efficiency are negative and statistically significant. Given the observed widespread over-application of labor, improved allocative efficiency entails a reduction in labor usage, which consequently diminishes output/revenue and thereby each dependent variable. In light of the results in Tables 3.8 and 3.12, then, it appears as if the omission of technical efficiency may bias the parameter estimates on land operated, at least for the land productivity and value added regressions. As such, it is necessary to reconsider those coefficient estimates. The estimates on the first-, second-, and third-order terms here maintain their signs as well as their statistical significance. As depicted graphically in Figure 3.9, which was created by fitting a third-degree polynomial least squares line to the predicted values of each regression (denoted LP, VA, and LU, respectively),³⁸ the first (second) inflection point occurs at 55 (138), 55 (138), and 51 (137) *manzanas* for each model, respectively. Once again, the overwhelming majority of producers in this sample – 94 percent in each case – operate landholdings below that of the first inflection point, which implies that a robust inverse relationship between operational landholdings and the three dependent variables continues to hold after controlling for technical and allocative efficiency.

Turning to Table 3.15 and Figure 3.10, for the sample of beans and maize producers, it is again evident that the coefficient on technical efficiency is positive and highly statistically significant for the land productivity and value added models. Further, regarding allocative

³⁸The predicted values for the labor usage regression are multiplied by ten so as to facilitate presentation.

Table 3.14: Fixed Effects Model Revisited (All)

	Land Productivity		Value Added		Labor Usage	
Variable	Coeff.	SE	Coeff.	SE	Coeff.	SE
d_{2001}	971.57***	130.36	774.84***	116.97	18.35**	9.32
d_{2005}	324.12*	175.44	760.39***	90.53	63.79***	6.35
Owned/Operated	-8.10	15.26	4.84	13.88	-0.11	0.64
Operated	-162.56***	16.76	-137.98***	10.60	-12.53***	0.75
Operated ² /100	226.27***	34.90	181.81***	21.00	16.94***	1.61
Operated ³ /1000	-8.27***	1.68	-6.40***	1.03	-0.60***	0.08
Male Labor	-86.68	66.17	-37.87	37.03	-0.93	2.64
Female Labor	-16.52	46.24	29.81	53.99	4.18	4.96
Share	-2.33	1.67	-9.23***	1.75	-0.22	0.14
TE	9,507.13***	1,206.14	5,372.22***	390.21	18.23	26.48
AE	-4,497.65*	2,678.48	-3,988.60**	1,856.24	-817.09***	155.54
R^2	0.62		0.73		0.80	
N	5,743		5,743		5,743	

* P-values <0.01, 0.05, and 0.10 correspond to ***, **, and *, respectively.

** Standard errors are bootstrapped with 1,000 replications.

efficiency, while insignificant in the value added regression, the coefficients remain negative and statistically significant for the land productivity and labor usage models. Accordingly, coupled with the results in Tables 3.8 and 3.12, it is evident that the parameter estimates on operational landholdings, for the land productivity and value added models, may again be subject to bias from the omission of technical efficiency. Returning, then, to the coefficients

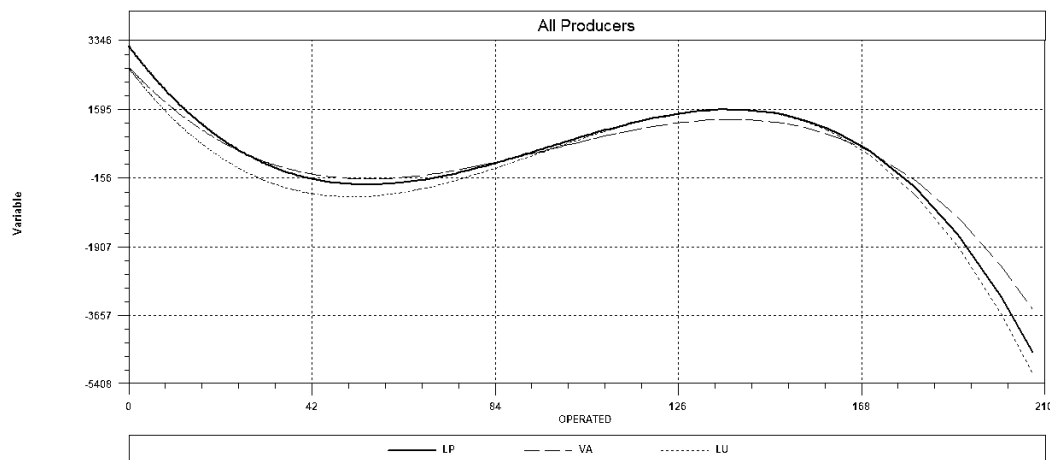


Figure 3.9: Operational Landholdings and Predicted Outcomes (All Producers)

on operational landholdings, it is apparent that, for each model, the parameter estimates maintain their signs and, though not for the third-order terms, statistical significance. As illustrated in Figure 3.10, the estimates imply that the first (second) inflection point occurs at 47 (130), 46 (129), and 44 (129) *manzanas* for each model, respectively, and we find that approximately 95 percent of producers operate landholdings below each of these values, which affirms that a robust inverse relationship between operational landholdings and each dependent variable remains for the majority of producers in this sample.

Table 3.15: Fixed Effects Model Revisited (Beans and Maize)

Variable	Land Productivity		Value Added		Labor Usage	
	Coeff.	SE	Coeff.	SE	Coeff.	SE
d_{2001}	773.00***	139.10	888.69***	138.52	1.98	9.80
d_{2005}	841.21***	132.61	1,033.89***	133.86	88.54***	12.32
Owned/Operated	-36.61*	20.35	-9.60	24.95	-0.29	2.13
Operated	-275.49***	86.42	-234.00***	73.64	-22.35***	6.02
Operated ² /100	590.82*	351.67	505.95*	286.34	46.02*	25.60
Operated ³ /1000	-31.97	34.67	-27.47	27.60	-2.41	2.59
Male Labor	-2.07	47.29	-66.74	52.66	-4.55	6.39
Female Labor	-69.17	59.14	-74.76	54.03	-0.58	5.85
Share	-5.41***	1.47	-6.58***	1.50	-0.13	0.17
TE	6,998.62***	457.87	5,766.08***	392.52	15.37	42.47
AE	-2,695.24**	1,362.32	-1,378.79	1,271.30	-663.11***	180.17
R^2	0.94		0.95		0.96	
N	2,596		2,596		2,596	

* P-values <0.01, 0.05, and 0.10 correspond to ***, **, and *, respectively.

** Standard errors are bootstrapped with 1,000 replications.

Regarding Table 3.16 and Figure 3.11, for the diversified producers, we see that the coefficients on technical efficiency remain positive and statistically significant for the land productivity and value added models whereas the parameter estimates on allocative efficiency, while negative for all models, only witness statistical significance for the labor usage regression. Thus, again in light of the results in Tables 3.8 and 3.12, there appears evidence that the omission of technical (in the land productivity and value added models) and allocative (in the labor usage regression) efficiency may bias the parameter estimates on operational landholdings. With respect to those estimates, then, for each model, we see that

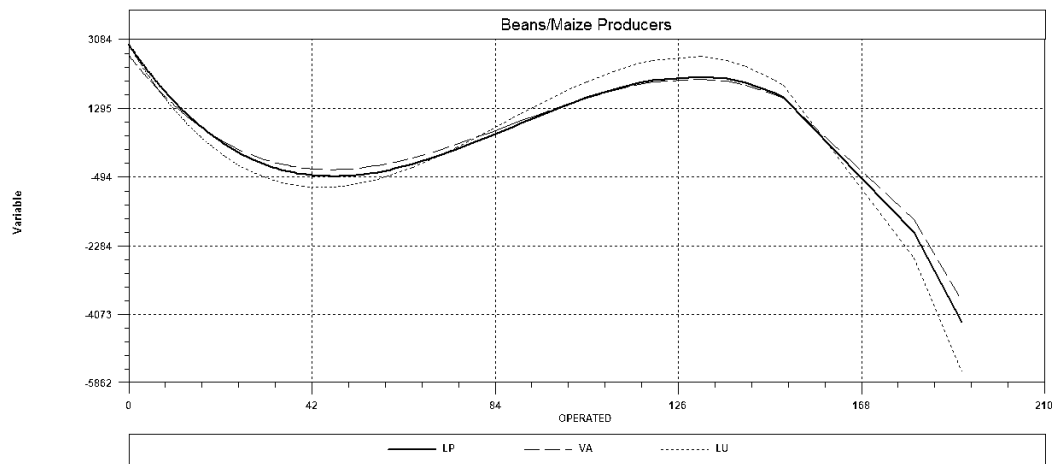


Figure 3.10: Operational Landholdings and Predicted Outcomes (Beans and Maize Producers)

each term in the third-order specification remains highly statistically significant and of the same sign as the initial models. Referencing Figure 3.11, the coefficients imply that the first (second) inflection point occurs at 58 (140), 59 (141), and 54 (140) *manzanas* for the three models, respectively, which once again suggests a persistent robust inverse relationship between operational landholdings and our dependent variables, as approximately 92 percent of producers in this sample operate landholdings below the first inflection point of all models.

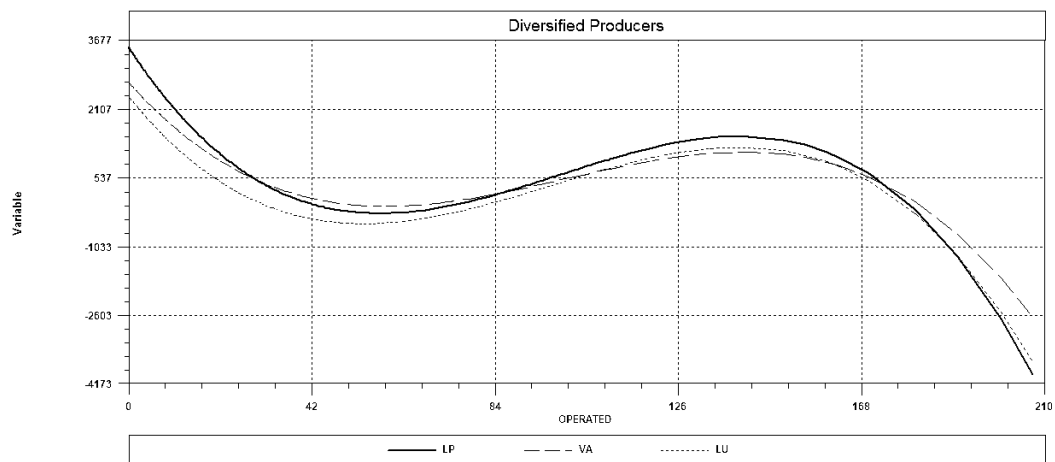


Figure 3.11: Operational Landholdings and Predicted Outcomes (Diversified Producers)

Table 3.16: Fixed Effects Model Revisited (Diversified)

Variable	Land Productivity		Value Added		Labor Usage	
	Coeff.	SE	Coeff.	SE	Coeff.	SE
d_{2001}	647.36***	142.18	403.91***	86.79	6.96	7.27
d_{2005}	181.74	303.03	635.03***	156.45	50.08***	8.77
Owned/Operated	15.70	24.91	20.14	26.54	-0.26	0.94
Operated	-149.28***	13.70	-136.23***	11.88	-9.80***	0.64
Operated ² /100	186.86***	27.89	167.82***	21.02	12.16***	1.22
Operated ³ /1000	-6.47***	1.37	-5.64***	0.98	-0.41***	0.06
Male Labor	-251.75	182.60	-147.79	91.14	-13.39***	4.23
Female Labor	19.47	102.13	52.14	68.60	3.27	5.05
Share	1.36	2.28	-4.92***	1.64	-0.23**	0.11
TE	8,703.27***	1,419.48	4,911.80***	509.79	-22.03	39.05
AE	-1,902.19	1,289.23	-778.44	580.02	-141.16***	20.78
R^2	0.84		0.88		0.86	
N	3,147		3,147		3,147	

* P-values <0.01, 0.05, and 0.10 correspond to ***, **, and *, respectively.

** Standard errors are bootstrapped with 1,000 replications.

Overall, as evidenced by the R^2 values, the final models possess non-negligible explanatory power. Thus far, however, we have confined our attention to the regressors of primary interest and have not examined the contribution of the other right-hand side variables. It can be seen from Tables 3.14-3.16 that the coefficients on the ratio of owned to operated landholdings as well as male and female labor are, for the most part, statistically insignificant for each model in each sample. Conversely, the parameter estimates on the share of income from off-farm activities frequently factor in negative and statistically significant, a finding that points to the importance of controlling for involvement in off-farm activities. Given the relatively small change in R^2 between the initial and revisited models, it therefore appears as if the explanatory power of the model is primarily driven by operational landholdings, the household-specific constants, and the share of income from off-farm activities. Finally, for all samples, given the persistent inverse farm size-labor usage relationship, it appears that the most likely explanation for the observed relationship between operational landholdings and land productivity as well as value added per unit of land operated is indeed found in labor market imperfections.

3.6 Conclusions

The 2007-08 world food crisis signaled the necessity of increasing global food supply and revived a long-standing debate surrounding the relationship between productivity/profitability and the size of agricultural landholdings. At the center of the debate, Oxford University's Paul Collier challenged years of empirical work supporting an inverse relationship, and called for the increasing implementation of large-scale commercial agriculture and the utilization of scale economies in skills and technology, finance and access to capital, and the organization and logistics of trading. Whether scale economies in these domains more than offset smallholder productivity/profitability advantages in land and labor usage is eminently an empirical question, especially given the time variant nature of technology, the working of financial markets, and changes in agri-food systems.

Focusing on the case of Nicaragua, we first critically examined the widespread empirical finding of an inverse relationship between farm size and productivity/profitability in developing countries, a phenomenon, it was contended, most reasonably attributed to labor market imperfections or (technical and/or allocative) efficiency differences between small and large producers. After discussing Nicaragua's nationally-representative LSMS-type panel data (for the years 1998, 2001, and 2005), we then elaborated upon a four-stage empirical framework so as to simultaneously investigate the existence and explanation of a robust relationship between farm size and productivity/profitability in Nicaragua's agricultural and livestock sector. Finally, in turning to the results of the analysis, it appeared that, while technical and allocative efficiency differences frequently exerted a statistically significant impact on alternative productivity/profitability indicators as well as across different samples, the explanatory power of these variables was evidently insufficient to rule out labor market imperfections as the driving force behind the observed inverse relationship.

So, what bearing do these conclusions have on the large body of theoretical work that has amassed in exploration of the inverse relationship? Sen (1966), pointing toward a substantial gap between wage rates outside the peasant economy and the real cost of labor inside, was among the first to formally suggest the existence of labor market imperfections

as an explanation for the observed productivity differential between small and large farms. However, Bhagwati and Chakravarty (1969) contended that the inverse relationship had been found to persist when empirically examining productivity disparities among only capitalist farms, which was said to, at the very least, render Sen's theoretical work incomplete. As a consequence, Eswaran and Kotwal (1986), acknowledging the fact that a multiplicity of market failures must be invoked to generate a systematic relationship between farm size and productivity, modeled an agrarian economy where heterogeneously-endowed agents faced imperfections in both labor and credit markets. In examining the equilibrium allocation of resources, then, the authors found land-to-labor ratios to be increasing in land endowments, which implied an inverse relationship between land productivity and land endowments, a result that was shown to exist independently within different modes of production. Thus, the theoretical explanation put forth in Eswaran and Kotwal (1986) not only appears consistent with much of the above-discussed empirical work on the inverse relationship, but also with the results of the present analysis.

CHAPTER 4

LAND DISTRIBUTION AND MODERN AGRICULTURAL VALUE CHAINS

4.1 Introduction

In developing countries, the steady advance of food demand – as induced by population growth, rising incomes, and increasing urbanization – is estimated to necessitate a near doubling of agricultural production by mid-century if higher and more volatile prices are to be avoided (FAO 2011b). With land scarcity, lackluster technical progress, and little remaining farm price repression, policy efforts aimed toward meeting such goals may indeed find solace in redistributive land reform¹ as the balance of empirical evidence suggests that smaller-scale producers possess a distinct productivity advantage in labor-abundant economies. However, the radical restructuring of global agri-food systems has raised questions as to whether space remains for redistribution to be welfare-enhancing (Lipton 2009). The increasing prominence of export horticulture, the rapid rise of supermarkets, as well as the proliferation of grades and standards have heightened the need for vertical coordination in agricultural value chains and resulted in the creation of modern procurement systems, the stringent quality standards of which credit-constrained, small-scale producers typically find difficult to meet (Eastwood et al. 2010). Thus, in recognition of the persistent growth of high-value markets, the objective of the analysis is to explore theoretically the efficiency

¹Land reform is here defined broadly as “legislation intended and likely to directly redistribute ownership of, claims on, or rights to current farmland, and thus to benefit the poor by raising their absolute and relative status, power, and/or income, compared with likely situations without the legislation” (Lipton 2009, 328).

of inequality in the distribution of agricultural landholdings in an agrarian economy characterized by credit and labor market imperfections as well as both traditional and modern value chains.

As contractual farming arrangements are central to the procurement systems of modern agro-industrial firms in developing countries, we develop an agent-based computational model that relies upon a four-stage conceptual framework of such arrangements as put forth in Barrett et al. (2012). First, following the spatial distribution of prospective growers, a monopsonistic agro-industrial firm chooses a procurement location based on attributes of candidate sites (i.e. proximity to prospective growers). Importantly, the prospective growers differ only in their (exogenously-given) quantity of land owned. Second, given the procurement location, the firm chooses, so as to maximize expected profit, the growers with whom to contract as well as the terms of those contracts (i.e. the procurement price). Third, the growers choose to accept or reject the offer depending on whether expected welfare under contractual participation exceeds reservation expected welfare. Finally, after the adjustment of factor prices, the firm and growers decide whether or not to behave opportunistically and renege on the terms of the contract. The model, then, for strategic alternative scenarios/parameterizations, consists of multiple iterations through these four stages, where each iteration is conducted on the basis of a different distribution of ownership landholdings and model outcomes (e.g. output, profit, poverty, etc.) are tracked accordingly.

The aforementioned framework represents an effort to generalize a highly-influential theoretical model developed by Eswaran and Kotwal (1986). The authors modeled an agrarian economy in which neoclassical agents face two primary constraints in their utility maximization problem: (1) a working capital or credit constraint where access to credit largely depends on the amount of land an agent owns and (2) a time constraint where hired labor is only an imperfect substitute for one's own labor time due to moral hazard. Given such constraints, the authors illustrated the emergence of a five-fold agrarian class structure where the class to which agents belong depends on their initial land endowment. Examining the equilibrium allocation of resources, then, the authors found land-to-labor

ratios to be increasing in land endowments, which implies an inverse relationship between land productivity and ownership landholdings. Accordingly, the model suggests that there exists scope for welfare-enhancing land transfers across agents. In positing, however, the existence of a unique market for the output of each agent, which is implicitly informal and “spot” in nature, the model fails to capture the essence of the new agricultural economy. To remedy this shortcoming, each agent in our model is additionally allowed to choose to incur, in return for the receipt of a price premium, the *fixed* cost (e.g. information search, physical capital investment, certification, etc.) associated with meeting the quality standards of the modern value chain. Thus, contingent on the premium embodied in the procurement price, within each grower class there can exist traditional and modern channel producers, and the decision as to which channel to choose is inextricably linked to the aforementioned constraints or market imperfections.

Sensitivity analysis reveals that the model results largely depend on the aforementioned fixed costs associated with meeting the quality standards of the modern value chain. Exploration of changes in this parameter reveals three possible outcome regimes that correspond to “low,” “intermediate,” and “high” fixed cost scenarios. Results from the “low” cost specification suggest that greater equity in ownership landholdings is seemingly in the interest of all parties in our agrarian economy as prospective grower and firm welfare increase monotonically in land ownership equality. Further, compared to a baseline specification without the presence of contractual farming arrangements (i.e. the original model formulation), for each iteration of this scenario welfare is strictly greater than that of the baseline. The “intermediate” and “high” cost scenarios, however, see the emergence of an equity/efficiency tradeoff. Regarding prospective growers, in both specifications welfare, above all, exhibits non-monotonicity in equality, at first increasing and then diminishing. While the firm witnesses similar non-monotonicity in profitability for the “intermediate” scenario, the “high” cost regime reveals that increased equity in ownership landholdings strictly decreases firm profit. Thus, the presence of, in some cases, an equity/efficiency tradeoff implies that policy efforts aimed toward redistributive land reform may require supplemental policy measures or *ex ante* empirical assessment to determine scope limi-

tations. Before discussing in further detail the agent-based model and results, it is first beneficial to elaborate upon the implications of the radical restructuring of global agri-food systems.

4.2 The Exclusionary Nature of Modern Value Chains

The inverse relationship between farm size and land productivity underpins the economic argument for land reform in developing nations. While Chayanov's (1925)² "labor-consumer balance," Sen's (1962) "dual labor cost" theory, and Schultz' (1964) "poor but efficient" hypothesis are perhaps the most influential assertions of the relative competitive power of smallholders, a great deal of empirical work has further amassed documenting the phenomenon in Africa (Cornia 1985; van Zyl et al. 1995), Asia (Yotopoulos and Lau 1973; Berry and Cline 1979; Carter 1984; Cornia 1985; Bhalla and Roy 1988), as well as Latin America (Barracough and Collarte 1973; Berry and Cline 1979; Cornia 1985; Deininger et al. 2003). The most common explanation for these findings resides in labor market imperfections whereby smaller, family farms witness a relatively low shadow price of labor – manifest empirically in increased labor usage per hectare – as their residual claimancy precludes the costly supervision of hired labor (Sen 1962; Carter 1984; Barracough and Collarte 1973; Heltberg 1998; Deininger et al. 2003). When imperfections in land or credit markets prevent the equalizing of factor ratios across producers, land reform, then, not only possesses the capacity to be output-enhancing and poverty-reducing among the landed, but can also generate welfare improvements among the landless, primarily through rising wages due to increased labor demand (Eswaran and Kotwal 1986).

Scale-biased participation in modern value chains has, however, raised questions as to whether efficiency gains from such redistribution remain sufficient to offset subdued economies of scale in, above all, finance and access to capital, as well as the organization and logistics of trading, marketing, and storage (Collier and Dercon 2009). Economies of scale in finance and access to capital, as will be seen, imply scale-variant grower capacity to meet the demands of high-value markets as formidable "up front" costs generally necessitate

²The work was translated into English in 1966.

credit for participation. Further, scale-invariant contract-related transaction costs suggest that larger-scale private trading and marketing could reduce costs, possibly via vertical integration or at least coordination. Accordingly, understanding the motivation for the research question, the theoretical approach, as well as the results of the analysis requires knowledge of the exclusionary nature of modern value chains. The following discussion then examines the radical restructuring of global agri-food systems that has occurred over the past few decades, the subsequent emergence of modern value chains and contractual farming arrangements, and, finally, the incentives (and constraints) that induce scale-biased participation in high-value markets.

4.2.1 The Radical Restructuring of Global Agri-Food Systems

Since the early 1980s, global agri-food systems have undergone a continual and fundamental transformation, which has been driven by four primary forces: (1) rising incomes; (2) increasing urbanization; (3) changing technology; and (4) globalization. On the demand side, rising incomes and increasing urbanization have affected such transformation mainly via dietary diversification, whereby higher value food items have displaced staples in consumer diets (McCullough et al. 2008). The impetus for dietary diversification given by rising incomes is well-known (Bennett's Law), but it is worth noting that urbanization induces dietary changes in a multitude of ways, such as growing female employment, access to greater variety, or even a heightened generalized exchange of ideas and culture. Crucially, the magnitude of these dietary changes is by no means negligible, as is evident in the 50 percent increase in per capita meat consumption that occurred in developing countries between 1990 and 2002 (Steinfeld and Chilonda 2006). Moving to the supply side, developments in procurement logistics technology and inventory management (e.g. Efficient Consumer Response) as well as the full or partial liberalization of developing economies fueled, above all, massive investments in food processing and retail throughout developing regions. Higher profit margins in developing nations coupled with market saturation and intense competition in developed nations has made such investment predominantly foreign in nature. The five- to ten-fold increase in overall FDI throughout the 1990s, a pattern

mirrored by FDI growth in food processing and retail, clearly illustrates the salience of technological developments and globalization (Reardon et al. 2008).

Resulting from the above transformative forces, change in global agri-food systems has manifest in the following inter-linked phenomena: (1) the increasing prominence of export horticulture; (2) the rapid rise of supermarkets; and (3) the proliferation of grades and standards (Eastwood et al. 2010). Concluded in 1993, the Uruguay Round and the accompanying Agreement on Agriculture marked a substantial liberalization of tariff and quantitative restrictions on trade in agricultural and food products. By 1996, developed nations had, on average, reduced tariffs on all agricultural products by 37 percent and those on tropical products by 43 percent (Henson and Loader 2001).³ Driven by such liberalization, food trade doubled (in volume and value) over the last two decades of the twentieth century. Perhaps more interestingly, the composition of the aforementioned trade also changed appreciably, namely from primarily commodity staples to product non-staples. For example, from 1980 to 2000, the share of bulk grains in international agricultural trade fell to 30 percent from 45 percent whereas trade in fruits and vegetables, meat and fish, as well as processed foods all increased significantly (Reardon and Timmer 2007). Among these compositional changes, the growth of export horticulture is generally considered most dynamic, as world trade in fruits and vegetables increased nearly 160 percent from 1980 to 2000 (Diop and Jaffee 2005).

While the growth of trade in agricultural and food products appears remarkable, such changes pale in comparison to the “avalanche” of FDI that followed the liberalization of capital markets. In 1980, for example, total FDI into both Asia and Latin America was approximately \$1 billion per year. By 2000, total FDI in both regions reached \$80-90 billion per year. Similar trends were also observed in Africa and Eastern Europe. Analogous to the case of trade, the composition of FDI also changed substantively. Throughout the liberalization period, food-related FDI increasingly shifted from “upstream” to “downstream” investments, namely investments in processing, retail, and food service (Reardon

³Statistics for tropical products are provided here as these products are of primary interest to developing countries.

and Timmer 2007). The diffusion of supermarkets, primarily in developing nations, has occurred at a particularly breathtaking pace. For example, garnering between 10-20 percent of national food retail sales in 1990, Latin American supermarkets were no more than a niche retail market that largely served wealthier consumers in major cities. By 2000, however, the supermarket share of food retail had risen to a noteworthy 50-60 percent. Latin American supermarkets, in a single decade, reached a level of development that took approximately fifty years in the United States. Notably, comparable patterns have been observed in East and Southeast Asia (e.g. Taiwan, the Philippines, and the Republic of Korea), Southern and Eastern Africa (e.g. South Africa and Kenya), as well as Central and Eastern Europe (e.g. Czech Republic, Hungary, and Poland), among other regions (Reardon and Berdegú 2002; Reardon et al. 2003; Dries et al. 2004).

Along with increasing consumer demand for product quality and developments in scientific knowledge, the liberalization of food supply chains has induced a counteracting proliferation of grades and standards, particularly in developed nations.⁴ In the public realm, such proliferation is adequately reflected in three regulatory acts: (1) the World Trade Organization's adoption (upon foundation in 1995) of Codex Alimentarius standards as the international reference point for the resolution of trade disputes, which was an action accompanied by the Agreements on the Application of Sanitary and Phytosanitary Measures (SPS) and Technical Barriers to Trade (TBT) in order to assure that grades and standards did not unnecessarily impede trade; (2) the General Food Law of the European Union (implemented in 2005), which introduced, among other stipulations, requirements on labeling, packaging, safety, and traceability; and (3) the United Kingdom's Food Safety Act (1990), which entailed that retailers demonstrate "due diligence" in the manufacture, transportation, storage, and preparation of food. Interestingly, many food retailers have responded to increasing public regulation by strategically supplementing such measures

⁴Following Reardon et al. (2001, 2), standards are defined broadly as "rules of measurement established by regulation or authority" and grades are defined as "a system of classifications based on quantifiable attributes." Such grades and standards are set at different levels (i.e. national, regional, or international), emanate from different sources (i.e. public or private entities), and apply to different product and process characteristics (e.g. quality standards, sanitary and phytosanitary measures, traceability regulations) (Swinnen and Maertens 2007).

with standards of their own. To cite a well-known example, in 1997 the Euro-Retailer Produce Working Group (EUREP) – an organization of 20 large European food retailers and purchasers – founded EUREPGAP/GLOBALGAP in order to meet consumer demands for safe, environmentally-conscious, and labor-friendly products. Similar private initiatives can be found in the British Retail Consortium (BRC) and Safe Quality Food (SQF) (Trienekens and Zuurbier 2008; Dolan and Humphrey 2000). Given that rising grades and standards in developed nations have been accompanied by analogous increases in developing regions (Reardon et al. 2008), most observers agree that in the past two decades “food standards have increased sharply and now play a central role in agri-food trade” (Swinnen and Maertens 2007, 414). With an adequate understanding of the transformation of agri-food systems, it is now possible to discuss the specific mechanisms by which agricultural production is linked to and impacted by this transformation.

4.2.2 Linking Growers to Modern Value Chains

As traditional wholesalers and brokers in developing nations typically rely on informal, “spot” transactions, the need for control over “upstream” entities (e.g. farmers) by “downstream” segments (e.g. modern retailers or export firms) necessitated by the agri-food system transformation has led to the bypassing of traditional value chains and required the parallel creation of modern procurement systems (McCullough et al. 2008; Reardon et al. 2009). Reardon et al. (2003, 2008) suggested that such modern procurement systems have been established on the basis of four key pillars. First, the increasing usage of specialized/dedicated wholesalers – those specialized in a specific product category and dedicated to modern retail, processing, or exporting firms – has served to cut transaction and search costs as well as enforce standards and contracts. Second, primarily in the case of supermarkets, there appears a shift away from per-store procurement practices and toward centralization through the growing utilization of distribution centers. Such a shift has served to increase efficiency and fuel expansion through the reduction of coordination, among other, costs (e.g. fewer procurement officers necessary). Third, quasi-formal and formal contractual arrangements have been increasingly employed in order to incentivize

producer investments in assets specific to retailer specifications. These arrangements, above all, have ensured on-time delivery of products of the desired quality. Finally, in addition to the above-discussed rising grades and standards, there is also an observed standardizing and harmonizing of product and delivery attributes across countries and regions, which is a process driven by multinational retailers in an attempt to continually reduce transaction costs.

Discussion of the impact on agricultural producers of modernizing procurement systems commonly centers on escalation in the prevalence of contractual farming arrangements, a phenomenon that has been documented in Africa (Warning and Key 2002; Boselie et al. 2003; Trienekens and Willems 2007; Neven et al. 2009; Barrett et al. 2012; Rao and Qaim 2011), Asia (Boselie et al. 2003; Simmons et al. 2005; Miyata et al. 2009; Stringer et al. 2009; Barrett et al. 2012), and Latin America (Blandon et al. 2009; Sáenz-Segura et al. 2010; Escobal and Cavero 2011; Michelson et al. 2011). According to Singh (2002, 1621), “[c]ontract farming refers to a system for the production and supply of agricultural produce under forward contracts, the essence of such contracts being a commitment to provide an agricultural commodity of a type, at a time and a price, and in the quantity required by a known buyer.” Such institutional arrangements allow agro-industrial firms to exert control over the production process to varying degrees depending on the chosen contract type, which can be of three (not mutually exclusive) varieties: (1) market specification; (2) resource-providing; and/or (3) production management. While binding firm and grower pre-harvest, market specification contracts are confined to governing the sale of the crop and conventionally specify price, quality, and timing conditions. In exchange for a marketing arrangement, resource-providing contracts additionally require that the agro-industrial firm provide production inputs (e.g. seeds or fertilizer), extension services, or credit. Finally, production management agreements further oblige growers to employ specific production methods or input regimens for which they receive marketing or resource-providing arrangements in return (Key and Runsten 1999). While empirical studies of the impact of contractual farming arrangements have highlighted the capacity of such agreements to raise grower welfare (e.g. via improved profitability and productivity)

and enhance rural development (e.g. positive multiplier effects for employment) (Warning and Key 2002; Simmons et al. 2005; Bolwig et al. 2009; Minten et al. 2009; Miyata et al. 2009), much research has struggled to establish causality and frequently highlighted scenarios where gains have been limited (Singh 2002; Sivramkrishna and Jyotishi 2008; Escobal and Caverro 2011; Barrett et al. 2012).

Two common limitations of contractual farming arrangements are particularly relevant at present: (1) monopsony power of contracting firms and (2) exclusion of smaller-scale, less capital-intensive producers. With respect to the first limitation, contract farming in developing country agriculture is frequently characterized by monopsonistic or oligopsonistic competition, whereby a single large buyer (or, at most, a few buyers) possesses the capacity to influence the terms (e.g. prices, quantities, quality, etc.) by which it contracts with multiple sellers. The rapid consolidation of supermarkets in developing countries is illustrative. In Latin America, 65 percent of the supermarket sector, on average, is controlled by the top five chains. In Guatemala, Costa Rica, and El Salvador these figures reach as high as 99, 96, and 85 percent, respectively (Reardon and Berdegúe 2002). Similar patterns of consolidation have been documented in Africa (Neven et al. 2009), Asia (Hu et al. 2004), as well as Central and Eastern Europe (Dries et al. 2004). Further, this consolidation typically occurs via foreign acquisition of local chains, as multinationals have access to investment funds from their own liquidity as well as the capacity to obtain cheap international credit that is not available to their domestic counterparts (Reardon et al. 2008). While the existence of a single, powerful buyer for contracted produce is a necessary but not sufficient condition for unequal bargaining strength – sufficiency requiring that growers also lack alternative opportunities – the consolidation and multinationalization of “downstream” segments has caused real concern that the potential benefits of contract farming are moderated by producer exploitation via the pricing of output or other non-price terms (Sivramkrishna and Jyotishi 2008).

Regarding the second limitation, the tendency for agro-industrial firms to eschew contracting with smaller-scale, less capital-intensive producers has emerged as a generalized occurrence in contractual farming relationships. In Latin America, such exclusion has been

observed in Brazil (Farina 2002), Costa Rica (Alvarado and Charmel 2002), Guatemala (Hernández et al. 2007), Mexico (Key and Runsten 1999), Nicaragua (Michelson et al. 2011), and Peru (Escobal et al. 2000; Escobal and Caverro 2011). African examples include Ghana (Trienekens and Willems 2007), Kenya (Dolan and Humphrey 2000; Neven et al. 2009; Asfaw et al. 2010; Rao and Qaim 2011), Senegal (Maertens and Swinnen 2009), South Africa (Trienekens and Willems 2007), and Uganda (Bolwig et al. 2009). Further, regarding Asia, exclusion has been documented in China (Stringer et al. 2009), India (Singh 2002), as well as Indonesia (Simmons et al. 2005). While less prevalent, a number of studies do point to cases where modern value chains have been inclusive of smallholders, but such exceptions to the general rule typically arise from one of the following special circumstances: (1) cooperatives or other farmer organizations act as an intermediary between contracting parties, as has occurred in Ghana (Barrett et al. 2012) as well as Honduras (Blandon et al. 2009); (2) outside assistance is provided to the contracting firm or participating producers as a result of partnerships between public and private sector stakeholders, which has been observed in Kenya, South Africa, Thailand, and Zimbabwe (Boselie et al. 2003); or (3) larger farms are simply a rarity in the relevant region, a phenomenon found in China (Miyata et al. 2009) as well as Madagascar (Minten et al. 2009). As high-value markets have continually gained retail share, the exclusionary nature of modern value chains has emerged as a particularly salient issue, a comprehensive understanding of which is of the utmost importance to the present analysis. Accordingly, the following examines in detail why smallholders are so commonly neglected.

4.2.3 Understanding Smallholder Exclusion

Examination of the incentive structure facing the contracting parties reveals that scale-biased participation arises from two sources: (1) scale-variant grower capacity to meet requisite standards and (2) scale-invariant contract-related transaction costs. Illustration of the first source of scale bias requires consideration of grower-side incentives and constraints, after the discussion of which we turn to the firm-side incentives and the second source of

scale bias. To begin, the primary costs of participation to growers can be categorized as follows:

(1) *Information*: Producers must obtain information on precisely how to meet the demands of the contracting firm, such as timing and frequency of delivery, growing crops with the desired characteristics (e.g. texture, shape, flavor, color, variety, etc.), or implementing any process-oriented requirements (e.g. chemical application) (Key and Runsten 1999). Informational considerations are particularly relevant in the case of market specification or “passive” procurement systems, whereby it is the choice, responsibility, and burden of the supplier to meet production and post-harvest requirements (Berdegúe et al. 2005). The commonly observed correlation between educational attainment and modern sector participation – a correlation documented, for example, in Guatemala (Carletto et al. 2010), Indonesia (Simmons et al. 2005), Kenya (Rao and Qaim 2011; Neven et al. 2009), Madagascar (Minten et al. 2009), as well as Peru (Escobal and Caverro 2011) – is indicative of the importance of information processing in overcoming the burden of these costs.

(2) *Physical Capital Investment*: Production and post-harvest requirements typically entail investments in irrigation systems, greenhouses, cold chain and transport, and/or hygiene facilities (Farina 2002). Among these investments, the usage of irrigation technology is of the utmost importance as “downstream” agents frequently emphasize the need to reduce sharp seasonality in production as well as enhance product quality. Further, when firms are seeking contracting partners, irrigation usage serves as a key observable indicator that a given grower has the capacity to meet the firm’s demands (Barrett et al. 2012). To cite a few examples, such a preference to contract with well-capitalized producers has been observed in China (Miyata et al. 2009), Croatia (Dries et al. 2004), Guatemala (Hernández et al. 2007), Indonesia (Simmons et al. 2005), Kenya (Neven et al. 2009; Rao and Qaim 2011), and Nicaragua (Michelson et al. 2011).

(3) *Certification*: Investment in the proper physical capital is commonly insufficient to ensure access to high-value markets. To demonstrate compliance with the standards of modern value chains, growers must additionally obtain certification under the relevant standard. For example, horticultural producers with product destined for the European Union must be EUREPGAP/GLOBALGAP certified, which necessitates, among other things, the development of a complete control and monitoring system – entailing thorough documentation of the variety/type, place of purchase, exact quantity, and planting/usage date of seeds and agro-chemicals used in the production process – as well as payment for external auditing, registration, training, and soil analysis. While estimation of these costs is rare, evidence for Kenyan horticultural producers suggests that they can exceed 20 percent of total annual crop income per farmer (Ashraf et al. 2009; Asfaw et al. 2010).⁵

(4) *Collective Action*: The formation of cooperatives or other farmer organizations is frequently touted as an effective means for smaller-scale producers to successfully gain entry to modern value chains by, among other things, lowering transaction costs, attracting contract offers, obtaining access to credit, as well as increasing bargaining power. However, development of the necessary human and social capital, the incurrence of membership and registration fees, as well as attending meetings and participating in planning and evaluation activities can be prohibitively costly (Blandon et al. 2009). The burden of these costs is evident in the fact that the successful establishment and continued operation of farmer groups commonly relies on outside assistance (e.g. from non-governmental organizations), as has been the case in Kenya (Neven et al. 2009), as well as Ghana, Mozambique, and Nicaragua (Barrett et al. 2012).

(5) *Input Usage*: Compliance with the demands of modern sector entities generally entails greater use of certified seeds, pesticides, chemical fertilizers, as well as labor.

⁵This estimate is based on an annual crop income of 123,333 Kenyan shilling (KSh) and incorporates the recurring cost of compliance (i.e. protective clothing, record keeping, salary for the grader, etc.) (6,700 KSh) as well as the aforementioned payments for external auditing, registration, training, and soil analysis (20,000 KSh).

The heightened need for quality assurance and/or control is the primary driving force in such increased input usage as contractual farming arrangements, as discussed, regularly require specific production methods or inputs regimens (e.g. pesticide application, soil maintenance, or post-harvest processing). Empirical evidence of rising variable input utilization is quite prevalent, instances of which can be found in Ecuador (Cavatassi et al. 2011), Guatemala (Hernández et al. 2007), Kenya (Neven et al. 2009; Rao and Qaim 2011), Nicaragua (Beuchelt and Zeller 2011), as well as Peru (Escobal and Cavero 2011).

As discussed, overcoming the obstacles to participation in modern value chains can, however, bestow significant benefits upon growers. The primary benefits are as follows:

- (1) *Output Prices*: Output price premiums are the principal motivation for selling in high-value markets. “Part of [the] difference [in output prices] is explained by quality difference, as contract prices include a premium for higher quality. . . . However, higher prices are also needed to avoid side-selling and to ensure contract enforcement.” (Minten et al. 2009, 1736). Further, not only do growers receive quality premiums and compliance incentives, but they may also capture a greater part of the marketing margin as modern supply chains are more direct and efficient than their traditional counterparts (Neven et al. 2009). Observed price premiums vary markedly, having been found to be as low as 10 and 15 percent in Kenya (Neven et al. 2009) and Uganda (Bolwig et al. 2009), but reaching magnitudes of 30 percent in Ecuador (Cavatassi et al. 2011), 40 percent in Madagascar (Minten et al. 2009), and even 130 percent in Indonesia (Simmons et al. 2005).
- (2) *Risk and Variability*: Contractual farming arrangements play an important role in the reduction of risk and variability. Modern sector firms are generally more stable and reliable, transactions and payments occur with greater frequency (sometimes year-round) thus smoothing seasonality, and output prices can be considerably less volatile. Reduced price volatility appears to be the primary mechanism by which risk and variability is mitigated, as is evident from research in China (Miyata et al. 2009), India

(Barrett et al. 2012), Kenya (Neven et al. 2009; Rao and Qaim 2011), and Nicaragua (Michelson et al. 2011). Concretely, estimation of price volatility reduction conducted in Nicaragua found coefficient of variation decreases as high as 60 percent when comparing Wal-Mart supplier price series to that of traditional channels (Michelson et al. 2011).

(3) *Resource Provision*: Markets for the specialized inputs (e.g. sophisticated irrigation and soil-monitoring equipment) required to produce for modern channels are commonly thin or missing in developing nations. As a result, agro-industrial firms seeking contractual farming arrangements must offer resource-providing or production management contracts as a means to overcome such market failures (Key and Runsten 1999). The *Arachide de Bouche* confectionary peanut program in Senegal is a particularly instructive example. Participating growers were provided seeds, fertilizer, and agro-chemicals on credit, a provision which was accompanied by close monitoring of agricultural practices. As a result of these services, participant yields were over 60 percent greater than those for oil peanuts. Notably, as a testament to the value participants placed on the mitigation of credit market failures, repayment rates reached 98-100 percent in normal agricultural years. Similar resource-providing arrangements have been found in Ghana (Barrett et al. 2012), Indonesia (Simmons et al. 2005), Madagascar (Minten et al. 2009), Mexico (Key and Runsten 1999), and Zimbabwe (Henson et al. 2005).

So, what do the grower-side incentives reveal about the exclusionary nature of modern value chains? The overwhelming majority of costs are fixed and “up front” in nature. Information search, physical capital investment, certification, and cooperative formation all fit this profile and, as such, act as a formidable deterrent to modern sector production. Coupling “up front” costs with the fact that the bulk of the above-discussed benefits accrue post-harvest, it is clear that there exists an intertemporal imbalance in net cash flows. As most producers necessitate credit to overcome these imbalances, access to such credit and the structure of credit markets are central to contractual farming arrangements. However, cash-strapped smallholders possess less capacity to self-finance and have limited

access to formal lending institutions due to lack of collateral (Key and Runsten 1999). Empirical evidence of such credit market imperfections is quite prevalent, especially in the wake of structural adjustment and the reduction of public expenditures for credit programs. In an influential analysis of access to capital in Kenya, Carter and Wiebe (1990) found a strong inverse relationship between the shadow price of capital and farm size, which is a clear assertion of credit-constrained small-scale production. Deoghare et al. (1991) as well as Sial and Carter (1996) documented similar credit market imperfections in India and Pakistan, respectively. Regarding Latin America, Barham et al. (1996), Jonakin (1997), as well as Carter and Olinto (2003) all provided evidence of significant wealth-biased liquidity constraints among agricultural producers in Guatemala, Nicaragua, and Paraguay, respectively. Thus, while only a snapshot of the literature on the issue, it is evident that credit market imperfections cannot be overlooked in examining the capacity of heterogeneous producers to participate in contractual farming arrangements.

Turning to firm-side incentives and the second source of scale-biased participation, contractual farming arrangements in developing countries primarily benefit agro-industrial firms through the minimization of the totality of transaction, production, and management costs (Herath and Weersink 2009). Understanding these benefits requires consideration of the firm's alternative options for organizing access to required inputs. At one extreme, "spot" markets are the preferred option for procurement of undifferentiated inputs (typically staple crops), but for non-traditional or specialized products (e.g. horticultural products) these markets are frequently unsuccessful in meeting quality and delivery requirements. Limited grower knowledge of and capacity to comply with quality requirements, firm and grower reluctance to invest in the requisite information and technology without a guaranteed market, and the costliness of coordinating deliveries of different farmers all occasion transaction costs that make "spot" market procurement an unattractive option for firms seeking differentiated product (Simmons et al. 2005). At the other extreme, vertical integration is common when high transaction costs are coupled with relatively low in-house production and management costs (Herath and Weersink 2009). However, when production is labor-intensive and economies of scale are absent, plantation-style agricul-

ture, which relies heavily on supervision to motivate wage labor, will incur relatively high production and management costs as residual claimancy of household labor used on family farms precludes supervision (Key and Runsten 1999). Thus, contract farming is an especially attractive intermediate option when labor-intensive agriculture intersects with stringent consumer quality demands, an intersection of immense importance based on the recent growth of contractual farming arrangements.

While the pursuit of contractual farming arrangements by an agro-industrial firm reflects the minimization of transaction, production, and management costs across available alternatives, such arrangements incur costs of their own and it is in the mitigation of these costs that arises the second source of scale-biased participation. Contract-related (transaction) costs include: (1) the search for prospective growers; (2) the screening of those growers; (3) the negotiation of contracts; (4) the transfer of goods, services, or property rights; (5) the monitoring of grower behavior; and (6) the enforcement of the terms of the contract. Crucially, the vast majority, if not all, of the aforementioned costs are fixed in nature and, thus, invariant to the scale of the contracted grower. By reducing the number of contracted growers or, equivalently, increasing their average scale, the agro-industrial firm can effectively minimize these contract-related transaction costs, which is an incentive that appears critical in the distribution of contracting opportunities (Key and Runsten 1999; Simmons et al. 2005). While estimates of contract-related transaction costs are scarce, the literature clearly shows that “high transaction costs can operate as an exclusion mechanism, affecting poorest farmers the most” (Escobal and Caverio 2011, 2).

In summary, then, the preceding discussion of the exclusionary nature of modern value chains has revealed a number of “stylized” facts that merit inclusion in the ensuing theoretical analysis. First, agricultural value chains in developing countries are commonly “dualistic,” whereby modern and traditional channels exist side-by-side. Second, modern channels are frequently characterized by monopsonistic competition. Third, “downstream” segments in the modern sector generally incur fixed contract-related transaction costs in return for the timely delivery of a quality product. Fourth, in order to reap the benefits of participation in high-value markets – namely price premiums – prospective growers typi-

cally must bear the burden of substantial fixed costs, an obstacle that credit-constrained smallholders find difficult to overcome. Finally, and perhaps most importantly, labor market imperfections in developing economies imply that smaller-scale family farms possess a distinct productivity advantage over that of their larger counterparts.

4.3 An Agent-Based Approach

An agent-based model consists of three basic elements: (1) agents; (2) an environment; and (3) rules. “Agents” are autonomous decision-making entities, each of which has its own internal state and behavioral rules. The “environment” is a medium separate from that of the agents, *on* and *with* which the agents interact. Finally, “rules” delineate the feasible set of actions and behavioral objective of the agents, thus governing *agent-agent* as well as *agent-environment* interactions (Epstein and Axtell 1996). Agent-based techniques are typically considered superior to other modeling approaches (e.g. equation-based modeling) when the system in question potentially requires considering the following: (1) spatial relationships; (2) heterogeneous agents; (3) complex agent behavior; and/or (4) non-linear, discontinuous, or discrete interactions. Accordingly, agent-based modeling entails simulating the behavior as well as interactions of a system’s constituent units (i.e. the agents), and capturing, from the bottom up, the emerging outcomes of interest (Bonabeau 2002). Building on these concepts and employing the ODD (Overview, Design concepts, Details) protocol as detailed in Grimm et al. (2006, 2010), the following outlines an agent-based approach to the theoretical exploration of the interrelationship between the distribution of agricultural landholdings, participation in contractual farming arrangements, and select aggregate outcomes.

4.3.1 Purpose

The objective of the analysis is to examine the efficiency of inequality in the distribution of agricultural landholdings in an agrarian economy characterized by credit and labor market imperfections as well as both traditional and modern value chains. To this end, noting that contractual farming arrangements are central to the procurement systems

of modern agro-industrial firms in developing countries, we seek to generalize a highly-influential theoretical model developed in Eswaran and Kotwal (1986) by embedding the model within a formalization of a four-stage conceptual framework of contractual farming arrangements as put forth in Barrett et al. (2012). As the formalization of the conceptual framework, in addition to subsequent simulations, entails the consideration of spatial relationships, heterogeneous agents, as well as complex agent behavior and interactions, an agent-based approach appears critical. Overall, then, such a formulation permits rigorous theoretical exploration of the relationship between equity in the distribution of ownership landholdings and select indicators (e.g. welfare, profit, output, etc.) in the presence of high-value markets.

4.3.2 Entities, State Variables, and Scales

The model is comprised of three basic entities: (1) a profit-maximizing agricultural commodity-processing or -distributing firm; (2) $N = N_0 + N_1$ uniquely- and randomly-located, utility-optimizing agrarian agents or prospective growers,⁶ where N_0 and N_1 are the number of landless and landed agents, respectively; and (3) the “environment.” Regarding state variables, the “environment” is characterized by the size/shape of a rectangular grid and the distribution of ownership landholdings among prospective growers, which is a function of the quantity of available land H and shape parameter δ . While the firm and prospective growers are both characterized by a grid location, it should be noted that the location of the firm is endogenous to the model, as discussed below. Additionally, the landed growers are assigned an index or rank $i = 1, 2, \dots, N_1$, which determines their endowment of ownership landholdings in each iteration. All other variables can be calculated from these elementary characteristics. Finally, with respect to spatial and temporal scale, the rectangular grid is adequately viewed as representing a subnational agricultural region⁷ (e.g. department, municipality, etc.) where successive iterations of the model, perhaps in-

⁶Note here that the term agent is used as a synonym for non-firm agricultural actors.

⁷Importantly, for the sake of simplicity, the spatial distribution of a given grower’s landholdings (i.e. whether such landholdings are contiguous or fragmented) has no bearing on production (i.e. fragmentation is assumed to be costless).

terpreted as consecutive agricultural cycles, entail an altered distribution of landholdings (i.e. an altered δ), which, as will be seen, ranges from a highly inequalitarian distribution ($\delta = 0.10$) to perfect equality ($\delta = 1$).

4.3.3 Process Overview and Scheduling

Figure 4.1 presents an Activity Diagram in Unified Modeling Language (UML) of the algorithm employed.⁸ First, we populate the rectangular grid with an exogenously-given quantity of land and a number of uniquely- and randomly-located (landed and landless) growers, where the landed are endowed with a quantity of landholdings as determined by an initial distribution of those holdings (i.e. $\delta = 0.10$). Second, on the basis of the location and land endowments of prospective growers, the modern agro-industrial firm, so as to maximize profit, chooses a procurement location from a subset of available locations. Third, via the profit-maximizing procurement price, the firm offers contractual farming arrangements to the desired prospective growers. Fourth, given their land endowments, the prospective growers, in order to optimize utility, choose whether or not to accept any contractual farming arrangements offered. Fifth, the contracting parties, after the adjustment of factor prices, decide whether or not to engage in opportunistic behavior and renege on the terms of the contract. Sixth, we record select model outcomes. At this point, if $\delta < 1$, the simulation is conducted anew, on the basis of initial locations, after an alteration in the distribution of ownership landholdings (via the incrementation of δ). If $\delta \geq 1$, the simulation is ended at perfect equality.

4.3.4 Design Concepts

Basic Principles

Drawing upon transaction cost, rational actor, and principal-agent theories, the model represents an attempt to explore theoretically the interrelationship between the distribution of agricultural landholdings, participation in contractual farming arrangements, and select aggregate outcomes. Specifically, as mentioned, we rely upon a four-stage con-

⁸Programming was conducted in Python 2.6.5 with specific reference to the template models put forth in Isaac (2011). See Appendix B for code.

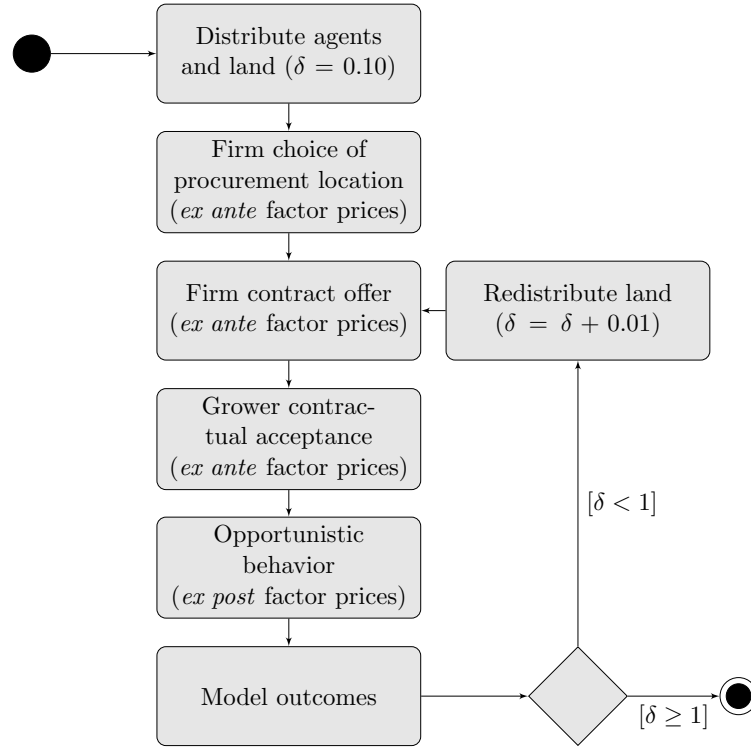


Figure 4.1: Activity Diagram

ceptual framework of contractual farming arrangements put forth in Barrett et al. (2012) in an effort to generalize a highly-influential theoretical model developed by Eswaran and Kotwal (1986).

Emergence

As stated, the model was designed to explore the relationship between select aggregate outcomes (e.g. welfare, profit, output, etc.) and the distribution of agricultural landholdings. Such model outcomes (further discussed below) are considered *weakly* emergent in the sense that they result from the decentralized decisions of autonomous entities.

Adaptation

Adaptation is permitted only in so far as the firm and prospective growers may choose to engage in opportunistic behavior after the adjustment of factor prices in each iteration. Extensions that allow for additional adaptation might include permitting reneged upon

actors to dynamically “update their prior beliefs based on each other’s (and third parties’) contract performance before re-evaluating the contract offer and acceptance decisions . . . in future periods” (Barrett et al. 2012, 720).

Objectives

Success is measured by the profitability and utility of the agro-industrial firm and prospective growers, respectively. The objective of the firm and growers, then, is to maximize success over the relevant decision variables while abiding by any constraints present.

Prediction

In selecting the profit-maximizing procurement location and contract offers (for the firm), and in deciding whether the acceptance of any such offers is utility-enhancing (for the prospective growers), the firm and growers implicitly predict that market clearing factor prices (i.e. the prices of land and labor) will remain unaffected by the introduction of contractual farming arrangements. Therefore, each actor is characterized by imperfect foresight and unaware of the general equilibrium effects of their actions.

Interaction

Two types of interactions are present in the model: direct and indirect. Direct interaction occurs via contractual farming arrangements. First, in each iteration, the firm communicates the profit-maximizing procurement price to prospective growers and the growers subsequently respond with their acceptance or rejection of the offer. Second, after the adjustment of factor prices, the firm and contracted growers relay their decisions regarding engaging in opportunistic behavior and reneging upon the terms of the contract. Indirect interaction occurs among prospective growers through the perfectly competitive markets for land and labor, by which the growers simply observe the market clearing factor prices.

Stochasticity

Stochasticity occupies a central position in the determination of firm and grower locations. First, prospective growers are located randomly on the aforementioned rectangular grid. Second, while the firm's choice of procurement location is determined via profit maximization, the candidate locations from which the firm selects are generated by random selection from available locations.

Observation

Observation entails the graphical depiction, for both the firm and prospective growers, of the relationship between select model outcomes (e.g. welfare, profit, output, etc.) and the distribution of ownership landholdings (i.e. δ).

4.3.5 Initialization

Table 4.1 presents the requisite state variables at initialization. While it is beneficial to refrain from comprehensive discussion of model parameterization until all parameters are introduced, two things in particular deserve brief mention. First, with respect to grid locations, the locations of the prospective growers and the candidate locations from which the firm selects are determined randomly,⁹ which precludes providing specific values at initialization. Second, regarding the indexes of the landed agents, as such agents are alike in every other respect, the definition of indexes is arbitrary, which again obviates the provision of specific values. Therefore, the initialization values presented below are precisely those required for replication.

4.3.6 Input Data

The model does not use input data to represent time-varying processes.

⁹Note, however, that the number of locations from which the firm selects is non-random. Within a reasonable range of values, the results of the model are insensitive to the chosen number of candidate locations. As such, the arbitrarily selected value is that which is presented in Table 4.1.

Table 4.1: Initialization

State Variable	Description	Value
N, N_0, N_1	Number of total, landless, and landed agents	100, 33, 67
Grid size	Dimensions of rectangular grid	20×20
H	Total quantity of available land	66
δ	Shape parameter on distribution of landholdings	0.10
Firm locations	Number of locations from which firm selects	100

4.3.7 Submodels

As noted, the model relies upon a four-stage conceptual framework of contractual farming arrangements as put forth in Barrett et al. (2012). Each submodel corresponds to a stage in this conceptual framework. After a detailed discussion of each stage, we then elaborate upon model outcomes and implementation.

Firm Choice of Procurement Location

The first stage in the conceptual framework entails the choice of procurement location of the agricultural commodity-processing or -distributing firm, a choice which is not necessarily confined to the region of sourcing, but may also include the location of warehouses and/or processing facilities. Agro-industrial firms typically take into account two primary factors when choosing their procurement location: (1) the agro-ecological suitability of the candidate regions for meeting quantity and quality requirements of the contracted commodity and (2) the transaction costs associated with procurement from a given region, which may include considering the endowments (i.e. land, labor, as well as physical, human, and social capital) and proximity of potential growers, transportation (e.g. road quality) and communication infrastructure (e.g. quality of phone service), or even the security situation (e.g. prevalence of crime). The chosen region, then, is that which maximizes the firm's expected profits subject to meeting or exceeding their reservation profit level. Such geographic targeting has clear ramifications for grower participation in contractual farming arrangements as those located outside the firm's chosen procurement

basin will, in the absence of other firms, face exclusion even if they possess the capacity to meet the requirements of the contracting enterprise (Barrett et al. 2012).

Specifically regarding the submodel, it is evident that the firm's choice of procurement location depends heavily on the attributes and dispersion of prospective growers. As such, building upon Eswaran and Kotwal (1986),¹⁰ we begin by populating the rectangular grid with an exogenously given quantity of land H and $N = N_0 + N_1$ uniquely- and randomly-located prospective growers where N_0 and N_1 are the number of landless and landed agents, respectively. Critically, land is homogeneous in quality and growers differ only in their quantity of land owned.¹¹ For a given landed grower $i = 1, 2, \dots, N_1$, let p_i denote the cumulative share of growers that own a lesser or equal quantity of land and, by assumption, let the proportion of land held by those p_i growers be determined by the Lorenz curve associated with a Pareto distribution:

$$F(p_i) = 1 - (1 - p_i)^\delta \quad (4.1)$$

where $0 < \delta \leq 1$ and larger values of δ induce a more egalitarian distribution of land. Accordingly, denoting the next smallest grower as p_{i-1} , the quantity of land owned ($\bar{h}$) by the i^{th} grower is derived from Eq. (4.1):

$$\bar{h}(p_i) = H [F(p_i) - F(p_{i-1})] = H \left[(1 - p_{i-1})^\delta - (1 - p_i)^\delta \right]. \quad (4.2)$$

The parameter δ is of primary importance here because it is the sole mechanism by which the land distribution is controlled. On the basis of an initial distribution of land, then, a monopsonistic agro-industrial firm chooses from a randomly-selected subset of (available) locations so as to maximize expected profit.

¹⁰For the sake of continuity, we adhere (as closely as possible) to Eswaran and Kotwal's notation.

¹¹Alternatively, the quantity of land owned by a given grower can be interpreted as an effective or quality-adjusted measure.

Firm Contract Offer

Given the procurement location, the second stage entails the firm's choice of growers with whom to contract as well as the terms of those contracts. Generally speaking, subject to meeting quality and quantity requirements, the firm seeks the constellation of contracted growers that maximizes expected profit levels. In the face of uncertainty surrounding the ability or desire of prospective growers to adhere to the terms of contractual arrangements, the firm typically identifies contracting parties by readily observable indicators, such as farm scale, access to irrigation, or participation in a farmer's organization (Barrett et al. 2012). Once prospective growers are identified, the firm commonly possesses the capacity to influence the content and form of the contracts (e.g. pricing, quantity, and quality of the contracted commodity), as contract farming in developing country agriculture, as discussed, is frequently characterized by monopsonistic competition. In selecting the profit maximizing contractual terms, however, the firm must incentivize grower participation by meeting or exceeding their expected reservation utility level. The procurement price, as mentioned, is the principal mechanism by which participation is incentivized, but it is important to note that, even if negotiating bilaterally, the firm conventionally pays uniform procurement prices (Sivramkrishna and Jyotishi 2008), which implies that some growers may receive welfare gains in excess of their reservation welfare. For example, in Mexico in the mid-1980s, Campbell's offered seven different types of contracts with an array of different procurement prices, but such differentiation was short-lived as implementation was costly and the firm was pressured by other plants to maintain procurement prices at a constant level and halt price discrimination (Key and Runsten 1999).

Moving to the submodel, in addition to the assumptions of monopsony power and uniform procurement prices, we add the following: (1) the firm, selling their product either wholesale or retail in urban or foreign markets, is assumed to be a price taker; (2) the firm has the option to procure commodities of the requisite quality from international markets, thereby setting their benchmark profit level, which is assumed to be zero; and (3) in exchange for timely delivery of a quality product, the firm incurs, in addition to

the aforementioned per-grower contract-related transaction costs, the costs of coordinating and transporting the product, which is assumed to be a function of the distance to the contracted growers (Barrett et al. 2012). As such, the objective function of the firm is as follows:

$$\Pi_F = P_F Q_F(\rho) - \rho Q_F(\rho) - K_F N_F(\rho) - GF(\rho). \quad (4.3)$$

The first term on the right-hand side of the above captures firm revenue, which is the (exogenous) output price for the firm's commodity P_F multiplied by the quantity of the commodity produced $Q_F(\rho)$, which is a function of the procurement price ρ . The second term on the right-hand side represents the cost of the purchased commodity, which is simply the procurement price multiplied by the quantity contracted. The third term represents the contract-related transaction costs, where $N_F(\rho)$ is the number of growers contracted and K_F is the per-grower contracting cost. Finally, the fourth term embodies coordination and transportation costs, where $F(\rho)$ is the sum of the (Euclidean) distances to the contracted growers and G is the cost per unit of distance. Such coordination and transportation costs play, above all, a central role in the choice of procurement location.

Before moving to the next stage, it is important to note that the functional forms for $Q_F(\rho)$, $N_F(\rho)$, and $F(\rho)$ are unknown to the firm. As will be seen, the prospective suppliers are a heterogeneous group, which engenders considerable complexity in their response to the price premium. On the basis of *ex ante* factor prices, then, the firm optimizes through a series of price premium calls by which it observes the quantity of growers willing to accept the contract, the quantity of product received from those growers, and the associated transaction costs, information from which the resulting profit is calculated (i.e. the optimization is numerical). As such, the firm's optimization of the stylized objective function is based on imperfect knowledge of the general equilibrium effects of their actions.

Grower Contractual Acceptance

Following the contract offer, the third stage concerns grower acceptance or rejection. Conceptually, the decision is straightforward: a prospective grower will accept the contract offer if his/her expected welfare under the arrangement is at least as great as his/her

reservation welfare (Barrett et al. 2012). While the incentive structure of contractual farming arrangements was thoroughly discussed above, the question remains as to what exactly is the reservation welfare. Although engaging in wage labor remains an option, transacting in the traditional, “spot” market is typically considered a prospective grower’s primary alternative (Hernández et al. 2007; Neven et al. 2009; Wang et al. 2009; Michelson et al. 2011; Rao and Qaim 2011). While prices in the traditional market, as discussed, are generally lower and/or more volatile, frequently production for this channel is substantially cheaper than that of the modern sector (Hernández et al. 2007; Miyata et al. 2009; Escobal and Cavero 2011; Rao and Qaim 2011) as “[p]rior commitments as to quality are not made, nor need producers commit to specific investments in order to sell under this arrangement” (Escobal and Cavero 2011, 6). Thus, traditional channel producers, unlike their modern sector counterparts, do not necessarily incur the costs of information search, physical capital investment, certification, etc., which is the primary reason traditional outlets remain a justifiable alternative.

Turning to the submodel, we further build on Eswaran and Kotwal (1986) by augmenting their specification of grower behavior with a contractual farming arrangement. Consequently, based on their land endowment, each grower optimizes their utility by choosing among three discrete activities: (1) modern sector grower (i.e. contract farming); (2) traditional sector grower; or (3) pure agricultural laborer. More concretely, we can write each grower’s optimal utility as follows:

$$U^* = \max\{U_M^*, U_T^*, U_L^*\} \quad (4.4)$$

where U_M^* , U_T^* , and U_L^* denote optimal utility as a modern sector grower, traditional sector grower, or pure laborer, respectively. In what follows, we discuss each of these optimization problems.

Given that the optimization problem facing the prospective modern or traditional growers are quite similar, we discuss both problems in parallel. As an agricultural producer, the objective of each grower is to maximize his/her utility subject to a (1) working

capital and (2) time constraint. Importantly, the constraints are directly influenced by two market “failures” ubiquitous in developing country agriculture: (1) the credit market as the quantity of working capital depends on an grower’s ability to provide collateral, which in turn depends on the quantity of land an agent owns; and (2) the labor market as hired labor has an incentive to shirk, which, thus, necessitates supervision and influences the time constraint. Beginning with production, growers produce output (q) with two essential inputs: land (h) and labor ($l + L$), where l and L are own and hired labor utilized, respectively. It is important here to carefully distinguish ownership landholdings ($\bar{h}$) from operational landholdings (h), as the two quantities can differ as a result of the leasing in or out of land. To account for the stochastic nature of agricultural production, we then write output as follows:

$$q = \varepsilon f(h, l + L) \quad (4.5)$$

where $\varepsilon \geq 0$ is a random variable with $E(\varepsilon) = 1$ and $f(h, l + L)$ is assumed to be homogeneous of degree one, increasing, strictly quasi-concave, and twice-continuously differentiable. Modern growers receive output price $\rho\beta P$, where $\rho \geq 1$ captures the price premium associated with participation in contractual farming arrangements, and βP is the present value of the “spot” or traditional market output price, which is the price received by traditional growers. Note here that $\beta \equiv 1/(1+r)$ is the discount factor and $r \geq 0$ is the exogenously-given interest rate per crop season. For convenience, βP is normalized to unity. Finally, the prices of land (v) and labor (w) are those that clear the (perfectly competitive) labor and land rental markets.

Regarding the working capital constraint, the quantity of working capital ($\bar{B}$) available to a given grower is determined by the amount of land that grower owns ($\bar{h}$), or $\bar{B} = \bar{B}(\bar{h})$ where $\bar{B}'(\bar{h}) > 0$. Further, in order to obtain modern sector price premiums, agricultural producers must incur certain fixed costs (K_M) including and in addition to those fixed costs associated with traditional production (K_T) (i.e. $K_M > K_T$). Importantly, given the linear homogeneity of the production function, these costs render cultivation on extremely small plots unprofitable and are partially responsible for the existence of a pure

laboring class (further discussed below). Then, denoting t as the quantity of labor sold on the labor market, we have the working capital constraint:

$$vh + wL + K \leq \bar{B} + v\bar{h} + wt \quad (4.6)$$

where K takes on the value of either K_M or K_T depending on the optimization problem at hand. Note here that the left-hand side represents outlays for production and the right-hand side is simply the quantity of available capital. Lastly, it is implicit in the above that all outlays are incurred at the beginning of the production period.

Moving to the time constraint, as $l + L$ is assumed to be the number of efficiency units of labor applied, from the knowledge of any two of q , h , or $l + L$, the presence of ε in Eq. (4.5) makes it impossible for an agent to know the value of the third. Therefore, unless given residual claimancy, all hired labor has the incentive to shirk, which suggests that each agent must supervise any hired labor. Assuming, then, that the amount of time each grower must supervise (S) is a function of the quantity of hired labor (L), we have $S = s(L)$ where $s'(L) > 0$ and $s''(L) > 0$. The conventional justification for the strict convexity of the supervision function is that it renders finite the size of the farm despite the linear homogeneity of the production function. Now, normalizing the amount of time available to a given grower to unity, we have four activities across which each grower can allocate that time: (1) working on his/her own farm (for an amount of time l); (2) supervising hired labor on his/her own farm (for an amount of time S); (3) selling his/her services on the labor market (for an amount of time t); or (4) leisure or rest (for an amount of time R). The time constraint is then written as follows:

$$l \equiv 1 - R - t - s(L) \geq 0. \quad (4.7)$$

Given the above working capital and time constraints, in defining the objective function we assume that all growers have identical preferences defined over the present value of earnings (Y) and leisure (R):

$$U = Y + u(R) \quad (4.8)$$

where $u'(R) > 0$, $u''(R) < 0$, and, of course, the precise specification of the objective function depends on whether we are considering prospective modern or traditional sector growers. Critically, the fact the utility function is linear in earnings implies risk-neutrality. Noting that the optimization problems for modern and traditional sector growers only differ in the prices received and the fixed costs incurred, below are presented the Lagrangians for both problems:¹²

$$\begin{aligned}\mathcal{L}_M = & \rho f[h, 1 - R - t - s(L) + L] - w(L - t) - v(h - \bar{h}) - K_M + u(R) \\ & + \lambda[B - w(L - t) - vh] + \mu[1 - R - t - s(L)] + \gamma L + \tau t\end{aligned}\quad (4.9)$$

$$\begin{aligned}\mathcal{L}_T = & f[h, 1 - R - t - s(L) + L] - w(L - t) - v(h - \bar{h}) - K_T + u(R) \\ & + \lambda[B - w(L - t) - vh] + \mu[1 - R - t - s(L)] + \gamma L + \tau t\end{aligned}\quad (4.10)$$

where $B \equiv \bar{B} - K + v\bar{h}$ and growers maximize over h , R , t , and L . The above, then, are standard Kuhn-Tucker problems where the unique solutions can be parameterized by B , the working capital. Accordingly, we have four possible modes of cultivation (i.e. classes),¹³ which are separated by three critical values B_1 , B_2 , and B_3 of B where $0 < B_1 < B_2 < B_3$ (see Appendix A for proof): (1) *Laborer-cultivator (LC)* where $0 \leq B < B_1$ and $t > 0$, $l > 0$, and $L = 0$; (2) *self-cultivator (SC)* where $B_1 \leq B < B_2$ and $t = 0$, $l > 0$, and $L = 0$; (3) *small capitalist (SM)* where $B_2 \leq B < B_3$ and $t = 0$, $l > 0$, and $L > 0$; and (4) *large capitalist (LG)* where $B \geq B_3$ and $t = 0$, $l = 0$, and $L > 0$.

As mentioned, it remains possible that a prospective grower can be made better off by simply choosing not to cultivate and becoming a pure agricultural laborer. The grower

¹²Note that the grower maximizes *expected* utility here.

¹³As a result of the fact that hired labor requires supervision, its effective cost exceeds the market wage. As such, it is never optimal for a grower to simultaneously sell his/her services on the labor market and hire labor on his/her farm (i.e. t and L cannot both be positive). Further, given that labor is an essential input to production, own labor (l) and hired labor (L) cannot simultaneously be zero.

will indeed choose not to cultivate if the following condition holds:

$$U_L^* > \max\{U_M^*, U_T^*\} \quad (4.11)$$

where U_L^* is determined via the following simple optimization problem:

$$U_L^* = \max_R w(1 - R) + u(R) + v\bar{h}. \quad (4.12)$$

Thus, with the addition of the class of pure agricultural laborers, there exists five possible classes of growers and, for those growers that choose to engage in own agricultural production, there exist modern and traditional grower subclasses.

Before moving forward, it is necessary to highlight one crucial feature of the above theoretical framework: in equilibrium there is a misallocation of resources and the optimal land-to-labor ratios, while constant for growers with $B < B_1$, are strictly increasing for $B \geq B_1$. As the growers effectively set the ratio of the marginal products of land and labor equal to the ratio of the perceived factor prices, increases in B (beyond B_1) induces a bias toward land in production as all growers face the same land price, but the perceived price of labor increases with B as growers optimally (1) consume less leisure, which raises the price of own labor, and (2) hire in (more) labor, the supervision cost of which increases at an increasing rate with the quantity hired. From the increasing land-to-labor ratios, it follows that expected land productivity, while constant for growers with $B < B_1$, is strictly decreasing for $B \geq B_1$ (see Appendix A for proof). Such a property is by no means incidental, but rather a central purpose of the model, which is to offer a coherent explanation for the routinely observed inverse productivity-size relationship. Therefore, there exists the potential for a transfer of resources to be welfare-enhancing.

Opportunistic Behavior

Finally, among the contracting parties there remains the possibility of reneging on contractual obligations. Generally speaking, the growers may choose to divert firm-provided inputs to non-contracted crops, refrain from adhering to the agreed upon produc-

tion schedule, engage in side-selling, and/or fail to make a timely delivery of a product of sufficient quantity and quality. The firm may simply choose not to pick up the contracted crop, inappropriately reject product, lower the procurement price post-harvest, and/or delay or default on the final payment. Informational asymmetries between contracting parties, the existence of market power, as well as costly contractual enforcement all create space for such breach of contract and, as a consequence, render important the selection of growers on unobservables such as trust, reliability, and reputation. While contractual breakdown has clear short-run welfare implications (e.g. payment default), the firm's delisting of underperforming growers, movement to other procurement regions, or pursuit of full vertical integration may carry significant longer-term consequences for the excluded parties (Barrett et al. 2012).

In the submodel, as discussed, the firm's profit maximization and subsequent contract offers are based on imperfect knowledge of the general equilibrium effects of their actions (i.e. the optimization uses *ex ante* factor prices), which creates room for opportunistic behavior once the factor prices have adjusted. "There may be an important fallacy of composition with scaling up participation . . . what is appealing to a single grower in the absence of general equilibrium effects may be less appealing once the system has fully responded and shifted expected returns" (Barrett et al. 2012, 719). As such, in observing the adjusted factor prices, growers under contract may indeed find it optimal to forego incurring the requisite fixed cost and sell their produce via traditional channels. Among those growers that choose to honor the agreement, the firm may find that the benefit received from retrieving the resulting output may not exceed the cost of doing so and, in such circumstances, the firm will refrain from retrieving the output, thereby leaving the growers to sell to traditional markets. Thus, before completion of the agreement, the firm and each contracted grower is allowed to reconsider whether the transaction is profit- or utility-enhancing and, if not, they possess the capacity to pursue alternative courses of action without retribution.¹⁴

¹⁴The short-term nature of the model precludes incorporating enforcement mechanisms in a substantive manner. As "a seriously understudied phenomenon" (Barrett et al. 2012, 720) in developing country agriculture, the inclusion of such mechanisms would, however, be largely speculative.

Model Outcomes and Implementation

As a final step in the discussion of the model, it is necessary to consider the primary outcomes of interest as well as elaborate upon implementation. Beginning with model outcomes, regarding the firm, four primary quantities are considered: (1) the price premium (ρ); (2) output (Q_F); (3) profit (Π_F); and (4) the proportion of growers *offered* a contract (p_c). The first three of these outcomes are self-explanatory and follow immediately from the above discussion of the firm's behavior. With respect to p_c , in order to reduce transaction costs, it is clear that the firm has a fundamental incentive to strategically exclude certain growers. To explore the extent of this exclusion, for each iteration of the model we simply calculate the proportion of prospective growers that were offered a contract. Moving to the grower-related outcomes, we also track four basic results: (1) aggregate utility (W); (2) aggregate output (Q); (3) the poverty rate (Z); and (4) the proportion of growers that successfully engaged in modern sector production (p_m). Aggregate utility and output are calculated via summation over individual grower utilities and output, and the poverty rate is constructed as the proportion of growers with income below a given poverty line. Regarding p_m , the aforementioned proportion of growers *offered* a contract does not account for opportunistic behavior on the part of the growers. As such, as an alternative measure of participation in high-value markets, we calculate p_m to gain insight not only into the frequency of successful completion of contractual farming arrangements, but also the extent to which opportunistic behavior occurs.¹⁵

With respect to implementation, two points deserve elaboration: (1) the rationale for maintaining constant locations throughout each simulation and (2) assumptions regarding functional forms and parameter values. Regarding locations, as is evident from Figure 4.1, the locations of the prospective growers and firm remain unchanged after being established in the first iteration. With randomly-located prospective growers, there appears no *a priori* rationale for their relocation in each iteration. The rationale for precluding

¹⁵Note here that we provide no measure of the extent to which the firm engages in opportunistic behavior. As contract-related transaction costs are incurred pre-harvest, the firm only reneges if, for a given grower, $Q_F(\rho)(P_F - \rho) < GF(\rho)$, which appears to be a rare, if not entirely absent, occurrence.

firm relocation, however, merits further consideration. For a given simulation, alternative values of δ can be interpreted as (1) temporal differences in the distribution of ownership landholdings for a given agrarian economy or (2) spatial differences in the distribution of ownership landholdings for alternative economies at, say, a given point in time. Noting that, for a given economy with temporal changes in the distribution of landholdings, firm relocation – whether it entails altering the region of sourcing or location of warehouses and/or processing facilities – is by no means costless and possibly prohibitively costly, we implicitly treat the firm’s initial investment as a sunk cost that has little bearing on the firm’s subsequent decisions. Thus, examining the sensitivity of the model’s results to alternative interpretations of changes in δ implies examining differences in outcomes when (1) throughout the simulation the firm remains in the location chosen in the first iteration (i.e. temporal differences specification) or (2) the firm is allowed to costlessly relocate in each iteration, which is functionally equivalent to the spatial differences specification. In comparing the alternative models, we find, surprisingly, that the results are qualitatively identical and quantitatively strikingly similar. In effect, keeping in mind that the incentive to contract with larger growers is unchanged across specifications, added flexibility in locational choice does not appear to appreciably alter the distribution of contractual offers and, thus, the outcomes of the model. Therefore, given that precluding firm relocation in each iteration reduces computational burden, the less complex specification is preferable.

Notably, then, as the firm’s choice of procurement location is based on the initial distribution of land, it would be unrealistic to begin the simulations at perfect inequality (i.e. $\delta \approx 0$). Lipton (2009) developed a five-fold categorization of developing countries on the basis of farmland inequality and contended that groups I and II (the most unequal) were “[t]he countries where very unequal land most suggests continuing need for land reform” (309). Using the author’s data, the average Gini coefficient for this combined group of 19 countries is 0.82, which translates into a δ value of approximately 0.10, a value at which it appears reasonable to initialize the simulation.¹⁶

¹⁶See Lipton (2009, 285-286) for the complete data listing. The Gini coefficients used in the calculation correspond to the most recent data, which spans the years 1990-2005. It is worth noting that the Gini

Moving forward, as analytical complexity necessitates a computational/numerical approach, explicit assumptions regarding functional forms and parameter values are required, all of which are provided in Tables 4.2 and 4.3. In an effort to facilitate continuity, all functional forms and the vast majority of parameter values are those utilized by Eswaran and Kotwal (1986). Thus, in the absence of a modern value chain, the present model is functionally equivalent to the original and yields qualitatively identical outcomes.¹⁷ Incorporation of contractual farming arrangements, however, requires four additional parameters: K_M , P_F , K_F , and G . Sensitivity analysis¹⁸ reveals that the model outcomes are largely insensitive to all additional parameters except K_M , and exploration of changes in K_M reveals three possible outcome regimes that correspond to “low,” “intermediate,” and “high” values of this parameter. Accordingly, in the ensuing discussion of the model results, we first present those outcomes that pertain to a baseline model with no modern sector, and then elaborate upon the model outcomes for each of these regimes.

Table 4.2: Assumed Functional Forms

Function	Description	Assumed Form	Parameter Domains
$f(h, L + l)$	Production function	$Ah^{1/2}(L + l)^{1/2}$	$A > 0$
$\bar{B}(\bar{h})$	Working capital availability	$\theta\bar{h} + \phi$	$\theta \geq 0, \phi \geq 0$
$s(L)$	Supervision function	$bL + cL^2$	$0 < b < 1, c \geq 0$
$u(R)$	Sub-utility function of leisure	$DR^{1/2}$	$D > 0$

coefficients utilized correspond to operated farmland and, thus, likely understate ownership inequality. The list of countries embodied in the two groups is as follows: Uruguay, Chile, Paraguay, Venezuela, Brazil, Argentina, Mexico, Costa Rica, Nicaragua, Colombia, Peru, Tunisia, Ecuador, Panama, Honduras, Saudi Arabia, Morocco, Iraq, and the Dominican Republic. Finally, note that $\delta = (1 - \text{Gini})/(1 + \text{Gini})$.

¹⁷While Eswaran and Kotwal (1986) used a continuum of growers, our model utilizes discrete growers. As such, the results presented are not quantitatively identical to the original model.

¹⁸Sensitivity analysis entailed: (1) determining a reasonable range/interval for the four parameters in question; (2) selecting a finite number of representative points in that range/interval for each parameter; (3) conducting the simulation for *every* possible combination of the resulting parameter values; and (4) examining the aforementioned model outcomes for each simulation.

Table 4.3: Model Parameterization

Parameter	Description	Value
A	Productivity parameter on production function	5
b	Parameter on first-order aspect of supervision function	0.3
c	Parameter on second-order aspect of supervision function	0.01
δ	Equality parameter on Lorenz curve	$[0.10, 1]$
D	Parameter on sub-utility function of leisure	0.1
G	Cost per unit of distance travelled for agro-industrial firm	0.5
K_F	Fixed costs for the agro-industrial firm	2
K_M	Fixed costs associated with modern value chain	0.75, 2, 3.25
K_T	Fixed costs associated with traditional value chain	0.5
P_F	Price for the firm's output	3.5
ϕ	Intercept of working capital function	0
P_L	Poverty line	1.3
θ	Parameter on land owned in working capital function	1

4.4 Results

Figure 4.2 presents the results from the baseline model with no modern sector (i.e. no firm). Before discussing the aforementioned agent outcomes, it is beneficial to briefly mention how equity in the distribution of *ownership* landholdings affects the allocation of *operational* landholdings among the four classes of producers. This exercise serves to illustrate that our results are not only in line with the original model but also reflect a wide range of observed agrarian class structures in developing countries. As the first panel illustrates, at very high levels of inequality (i.e. $\delta \approx 0.10$) large capitalist (LG) farming dominates (e.g. South and Central America), but as the distribution of landholdings becomes more equitable (i.e. $\delta \rightarrow 1.0$) it is clear that small capitalist (SM) enterprises prevail (e.g. East and Southeast Asia) (Note that LC and SC denote the laborer-cultivator and self-cultivator classes, respectively). In general, this result holds for all subsequent scenarios considered and, as such, we refrain from its repeated presentation.

Regarding the second panel and agent outcomes, it is evident that greater equality in the distribution of landholdings not only generates distinct welfare (W) and output (Q)

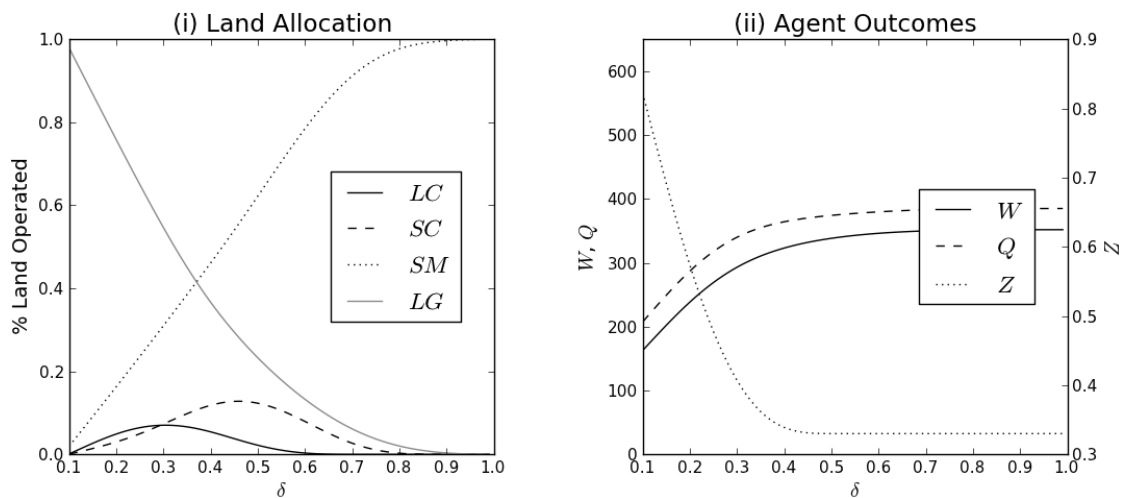


Figure 4.2: Baseline Model

increases, but also leads to sharp reductions in the poverty rate (Z). “The increase in social welfare is a direct consequence of the inverse relationship between farm size and land productivity . . . a move toward a more egalitarian land ownership distribution increases the aggregate output” (Eswaran and Kotwal 1986, 494). Landless agents are by no means excluded from these welfare gains as, even though they remain landless throughout the entire simulation, increased equality boosts labor demand, which unambiguously drives up the equilibrium wage rate.¹⁹ As mentioned, however, with fixed costs deterring landless agents from engaging in agricultural production, the persistent 33 percent poverty rate implies that the wage increases remain insufficient to pull these agents out of poverty.²⁰ Overall, then, in the absence of modern value chains, there appears no discernible equity/efficiency tradeoff, which is a result we use as a benchmark for subsequent simulations.

Allowing, now, the possibility of contractual farming arrangements, Figure 4.3 presents the results from the “low” K_M ($= 0.75$) regime. In the first panel, in addition to inducing full participation of landed agents in the modern sector (i.e. $p_m \rightarrow 0.67$), it is again clear

¹⁹At $\delta = 0.10$, the wage rate equals approximately 0.07, and as $\delta \rightarrow 1.0$ the wage approaches 0.99.

²⁰The poverty line utilized, however, is largely arbitrary. The point to be emphasized here is that, from the perspective of the landless agents, the gains from a more egalitarian distribution of ownership landholdings are limited, as they remain concentrated at the low end of the income spectrum throughout the simulation.

that greater equity in ownership landholdings reduces agent poverty as well as increases aggregate welfare and output. Crucially, however, for each iteration of the model (i.e. for each δ) welfare and output are strictly greater than that of the baseline scenario. While the receipt of price premiums incentivizes increased output, the firm's payment of uniform procurement prices implies that only the marginal grower is bid down to his/her reservation utility, which generates the welfare effect as the utility of all other growers exceeds that of their reservation level. Further, it should be noted that increased labor demand remains insufficient to completely eradicate poverty among the landless.

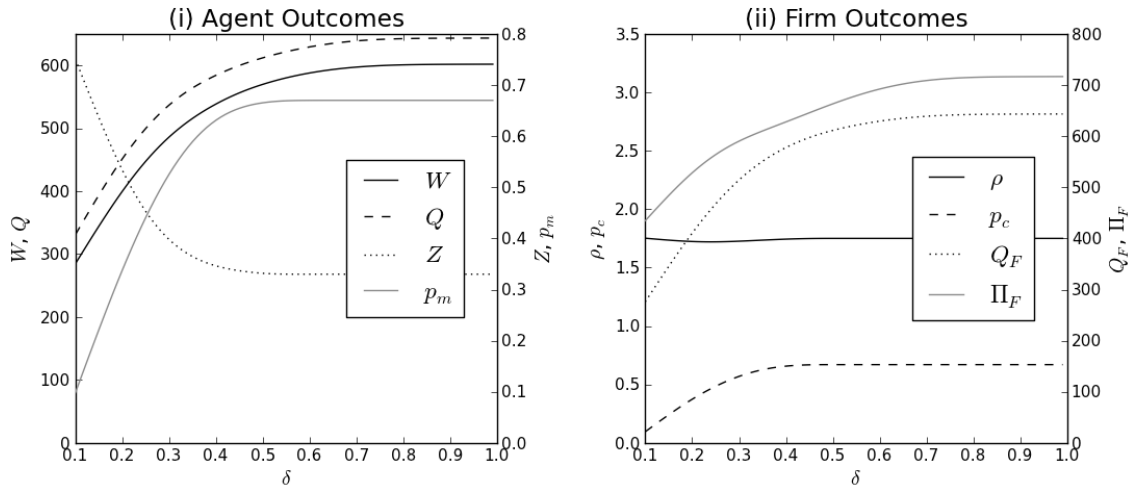


Figure 4.3: Low K_M Regime

In the second panel, the firm appears to play a passive role, maintaining a relatively constant procurement price (i.e. $\rho \approx 1.75$ for each iteration) and allowing prospective growers to opt in to contractual farming arrangements if/when they reach a scale at which such arrangements are welfare-enhancing, a phenomenon implied by the increasing nature of the proportion contracted (i.e. p_c). As greater equality leads to increased firm output (Q_F) and profitability (Π_F), an egalitarian distribution of ownership landholdings, at low levels of K_M , is seemingly in the interest of all parties in our agrarian economy. Finally, in comparing p_m and p_c it is clear that opportunistic behavior, on the part of the contracted agents, is nearly absent as these quantities remain largely identical throughout the simulation.

Turning to the “intermediate” K_M ($= 2.0$) regime, Figure 4.4 illustrates the emergence of an equity/efficiency tradeoff. In the first panel, while the poverty rate again decreases unambiguously, now agent welfare and output exhibit non-monotonicity in δ . While welfare and output still remain above that of the baseline for each iteration, both indicators in this scenario fall below those of the “low” K_M regime for the corresponding δ . Of primary interest here, however, is why the non-monotonic relationship manifests. The reasoning behind this phenomenon is found primarily in the fact that the proportion of growers that successfully contract (i.e. p_m) is increasing in δ for $\delta \leq 0.55$, but decreasing for $\delta > 0.55$. Thus, as δ traverses the interval $[0.10, 0.55]$, in addition to the welfare gains derived from the inverse relationship between farm size and land productivity, the increasing proportion of agents attaining price premiums generates an analogous welfare premium and incentivizes increased output. As p_m , however, decreases with additional increments in δ , the welfare premium and incentives toward enhanced output are eroded by further equality. Thus, at “intermediate” levels of K_M , there remains no direct relationship between agent welfare/output and the equitable distribution of ownership landholdings.

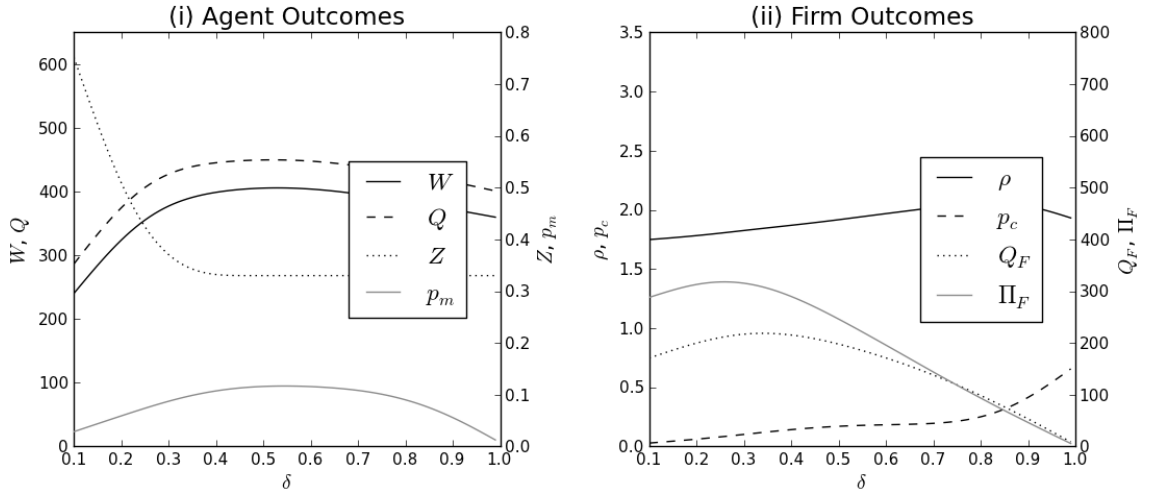


Figure 4.4: Intermediate K_M Regime

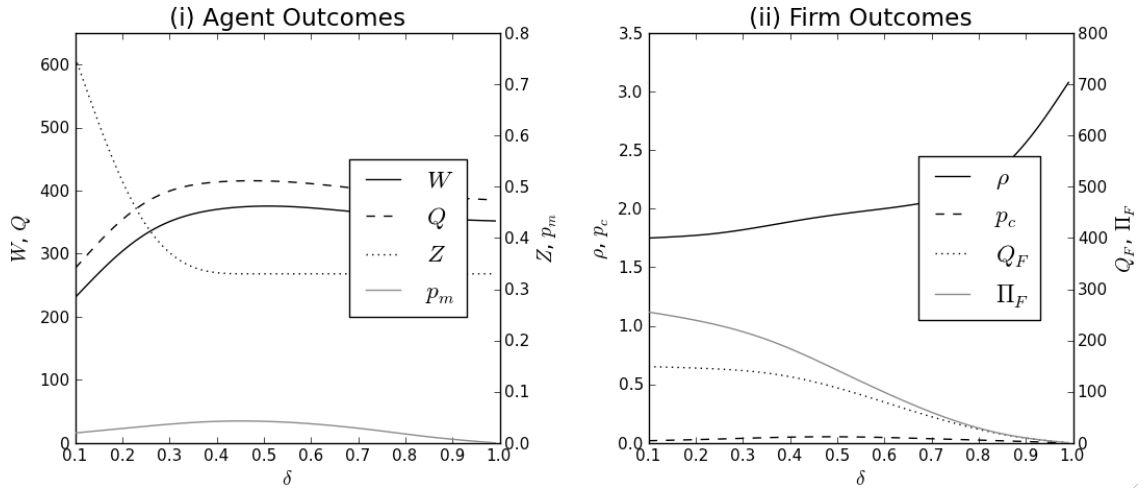
With respect to the second panel, the equity/efficiency tradeoff presents itself more starkly yet. For high levels of inequality (i.e. $\delta < 0.3$), the firm again maintains a relatively constant procurement price and passively profits from induced equality. However,

as greater equity is achieved (i.e. $\delta > 0.3$), the firm witnesses steep decreases in output and profit, a phenomenon unsuccessfully combated with higher procurement prices. Interestingly, as perfect equality is achieved, the firm in fact presents all landed agents with a contract offer (i.e. $p_c = 0.67$), but general equilibrium effects prevail and virtually no agents find it optimal to conclude the agreement successfully. Therefore, not only does the “intermediate” scenario see the emergence of a definitive equity/efficiency tradeoff, but it also gives rise to non-negligible opportunistic behavior.

Figure 4.5 presents the results from the “high” K_M ($= 3.25$) regime. As the agent outcomes in the first panel are largely identical to those of the previous scenario, it is beneficial to focus on the second panel and the firm-related outcomes. The defining characteristic of the “high” K_M regime is that firm output and profit are now monotonically decreasing in δ . In this scenario, only agents of the largest scale find it welfare-enhancing to engage in contractual arrangements, and with increased equality the average scale of these agents unambiguously diminishes. Even though the proportion of contracted agents initially increases, albeit slowly, this scale effect dominates throughout, which induces monotonic decreases in output and, coupled with the fact that the firm counters with higher procurement prices, profit as well. Finally, it is also important to note that the opportunistic behavior observed in the “intermediate” scenario altogether disappears here as the firm finds that, at a relatively egalitarian distribution of ownership landholdings, the requisite procurement price is too high to justify even initiating any contractual offers.

4.5 Conclusions

Agricultural value chains in developing countries have undergone considerable change as a result of dietary diversification as well as the food-related trade and foreign direct investment growth that has accompanied liberalization/globalization. The increasing prominence of export horticulture, the rapid rise of supermarkets, in addition to the proliferation of grades and standards have heightened the need for vertical coordination and resulted in the creation of modern procurement systems, the stringent quality standards of which credit-constrained, small-scale producers typically find difficult to meet. Even though

Figure 4.5: High K_M Regime

the balance of empirical evidence suggests that, due to a relatively low shadow price of labor, smaller-scale producers continue to possess a distinct productivity advantage in labor-abundant economies, the radical restructuring of global agri-food systems has raised questions as to whether redistributive land reform remains a viable policy option in efforts aimed toward meeting aggressive agricultural production targets. In this context, the present study developed an agent-based computational model to explore the efficiency of inequality in the distribution of agricultural landholdings in an agrarian economy characterized by credit and labor market imperfections as well as both traditional and modern value chains.

Fixed transaction costs associated with contractual farming arrangements, namely those incurred by growers in meeting the quality standards of the modern value chain (i.e. information search, physical capital investment, certification, etc.), emerge as the primary intermediary of the relationship between equity in the distribution of agricultural landholdings and the efficiency of aggregate outcomes (i.e. welfare, profit, output, etc.). Exploration of changes in this parameter reveals three possible outcome regimes that correspond to “low,” “intermediate,” and “high” transaction cost scenarios. Results from the “low” cost specification suggest that greater equity in ownership landholdings is seemingly in the interest of all parties in our agrarian economy as the welfare of prospective growers

and monopsonistic agro-industrial firm increase monotonically in land ownership equality. Further, compared to a baseline specification without the presence of contractual farming arrangements, for each iteration of this scenario welfare is strictly greater than that of the baseline. The “intermediate” and “high” cost scenarios, however, see the emergence of an equity/efficiency tradeoff. Regarding prospective growers, in both specifications welfare, above all, exhibits non-monotonicity in equality, at first increasing and then diminishing. While the firm witnesses similar non-monotonicity in profitability for the “intermediate” scenario, the “high” cost regime reveals that increased equity in ownership landholdings strictly decreases firm profit. Thus, the presence of, in some cases, an equity/efficiency tradeoff implies that policy efforts aimed toward redistributive land reform may require supplemental policy measures or *ex ante* empirical assessment to determine scope limitations.

APPENDIX A

SELECT PROOFS

The following proofs are adapted from Eswaran and Kotwal (1984). While the proofs correspond closely to the original formulation, the exercise serves to illustrate that the basic results hold for the augmented model. Given that the objective functions presented in Eqs. (4.9) and (4.10) are twice continuously differentiable, by assumption, from the Implicit Function Theorem it is evident that the solutions are continuous in the parameters. In what follows, all arguments of the solutions except B are suppressed. In addition, we assume that the working capital constraint is binding throughout (i.e. $\lambda > 0$). Thus, we can solve the working capital constraint for h , which yields $h = (B + wt - wL)/v$. Further, as the optimization problem for traditional sector production is a special case of that for modern sector production, we focus here on the general case. In what follows we first establish the ranges of B over which each mode of production is manifest and then examine the relationship between expected output per hectare and land endowments.

A.1 Endogenous Class Formation

Beginning with the laborer-cultivators, as $t > 0$, $l > 0$, and $L = 0$ for this class of producers, the first-order conditions are as follows:

$$\frac{\partial \mathcal{L}_M}{\partial R} = -\rho f_2[(B + wt)/v, 1 - R - t] + u'(R) = 0, \quad (\text{A.1})$$

$$\frac{\partial \mathcal{L}_M}{\partial h} = \rho f_1[(B + wt)/v, 1 - R - t] - v(1 + \lambda) = 0, \quad (\text{A.2})$$

$$\frac{\partial \mathcal{L}_M}{\partial t} = -\rho f_2[(B + wt)/v, 1 - R - t] + w(1 + \lambda) = 0. \quad (\text{A.3})$$

Totally differentiating the above first-order conditions with respect to B , we have the following:

$$\begin{bmatrix} [f_{22} - (w/v)f_{21}] & [f_{22} + u''/\rho] & 0 \\ [(w/v)f_{11} - f_{12}] & -f_{12} & -v \\ [f_{22} - (w/v)f_{21}] & f_{22} & w \end{bmatrix} \begin{bmatrix} \frac{\partial t^*}{\partial B} \\ \frac{\partial R^*}{\partial B} \\ \frac{\partial \lambda^*}{\partial B} \end{bmatrix} = \begin{bmatrix} f_{21}/v \\ -f_{11}/v \\ f_{21}/v \end{bmatrix}. \quad (\text{A.4})$$

Denoting the determinant of the matrix on the left-hand side above as Δ , by the strict concavity of $u(\cdot)$ and strict quasi-concavity of $f(\cdot, \cdot)$, it is readily shown that $\Delta < 0$. Then, invoking Cramer's rule, we have:

$$\Delta \frac{\partial t^*}{\partial B} = (w/v)(f_{11}f_{22} - f_{12}^2) + (u''/\rho)[(w/v)f_{11} - f_{21}] \quad (\text{A.5})$$

where it follows from the linear homogeneity and strict quasi-concavity of $f(\cdot, \cdot)$ that $f_{11}f_{22} - f_{12}^2 = 0$, $f_{11} < 0$, $f_{22} < 0$, and $f_{21} > 0$. Thus, it is evident that $\partial t^*/\partial B < 0$. Recalling that land is an essential input, if $t = 0$ at $B = 0$, then the marginal product of land would be infinite. Accordingly, it is necessary that $t^*(0) > 0$, which implies that there exists a range of values $[0, B_1)$ of B where $t^*(B) > 0$ and B_1 marks the transition to self-cultivation.

Turning to the small capitalists, as $t = 0$, $l > 0$, and $L > 0$ for this class of producers, we have the following first-order conditions:

$$\frac{\partial \mathcal{L}_M}{\partial R} = -\rho f_2[(B - wL)/v, 1 - R - s(L) + L] + u'(R) = 0, \quad (\text{A.6})$$

$$\frac{\partial \mathcal{L}_M}{\partial h} = \rho f_1[(B - wL)/v, 1 - R - s(L) + L] - v(1 + \lambda) = 0, \quad (\text{A.7})$$

$$\frac{\partial \mathcal{L}_M}{\partial L} = \rho f_2[(B - wL)/v, 1 - R - s(L) + L][1 - s'(L)] - w(1 + \lambda) = 0. \quad (\text{A.8})$$

Noting that $\partial L^*/\partial B > 0$ for this class of producers (shown in Section A.2), let B_2 indicate the value of B where $L^*(B_2) = 0$ (i.e. the value of B where small capitalist production emerges). As Eq. (A.8) barely continues to hold with equality, we can write the following:

$$\rho f_2[B_2/v, 1 - R][1 - s'(0)] - w(1 + \lambda) = 0. \quad (\text{A.9})$$

Given that t and L cannot simultaneously be positive, it is evident that $B_2 \geq B_1$. To establish that B_2 is strictly greater than B_1 , assume for the moment that $B_2 = B_1$. As Eq. (A.3), then, barely holds with equality at B_1 , we have:

$$\rho f_2[B_2/v, 1 - R] - w(1 + \lambda) = 0. \quad (\text{A.10})$$

Given the uniqueness of the solution, the values of R and λ must be identical in Eqs. (A.9) and (A.10). Therefore, as long as $s'(0) > 0$, Eqs. (A.9) and (A.10) cannot simultaneously hold, which implies that $B_2 > B_1$.

It has been shown, then, that when $B \in [0, B_1)$ laborer-cultivation is manifest, when $B \in [B_1, B_2)$ we have self-cultivation, and when $B \geq B_2$ the capitalist mode of production is obtained. For the self-cultivators, in Section A.2 we will see that $\partial R^*/\partial B < 0$ or conversely $\partial l^*/\partial B > 0$ as $l^*(B) = 1 - R^*(B)$ for this class of producers. Given that $l^*(B_2) > 0$, it follows that the large capitalist mode of production emerges at some value $B_3 > B_2$ when $l^*(B_3) = 0$, which is implied by the continuity of l^* in B . Thus, small capitalist production is obtained when $B \in [B_2, B_3)$ and large capitalist production when $B \geq B_3$.

A.2 Expected Output Per Hectare

Let $n = l + L$ and as $f(h, n)$ is linearly homogeneous, increasing, and strictly quasi-concave, we can write the following:

$$f(h, n) = ng(x) \quad (\text{A.11})$$

where $x \equiv h/n$, $g'(\cdot) > 0$, and $g''(\cdot) < 0$. As expected output per hectare is $ng(x)/h = g(x)/x$, the following partial derivative is of particular interest:

$$\frac{\partial}{\partial B}[g(x)/x] = \left[\frac{xg'(x) - g(x)}{x^2} \right] \frac{\partial x^*}{\partial B}. \quad (\text{A.12})$$

By the strict concavity of $g(x)$, it follows that $xg'(x) - g(x) < 0$. Thus,

$$\text{sign} \frac{\partial}{\partial B} [g(x)/x] = -\text{sign} \left(\frac{\partial x^*}{\partial B} \right). \quad (\text{A.13})$$

In order to determine, then, the relationship between output per hectare and land endowments (as represented by B), we examine, for each class of producer, the relationship between x^* (i.e. the optimal land-to-labor ratio) and B . Given the above, the agent's optimization problem for modern sector production can be conveniently rewritten as follows:

$$\max_{t, R, L} \rho n g(x) - B + v\bar{h} + u(R) \quad (\text{A.14})$$

where $n \equiv 1 - R - t - s(L) + L$ and $x \equiv (B + wt - wL)/vn$ is the land-to-labor ratio.

Beginning with laborer-cultivators, as $L = 0$ for this class of producers, the choice variables are t and R . The first-order conditions are as follows:

$$\frac{\partial U_M}{\partial R} = -\rho g(x) + \rho x g'(x) + u'(R) = 0, \quad (\text{A.15})$$

$$\frac{\partial U_M}{\partial t} = -\rho g(x) + \rho g'(x)(w/v + x) = 0. \quad (\text{A.16})$$

Eq. (A.16) can then be rewritten as $[g(x) - xg'(x)]/g'(x) = w/v$, the solution to which determines the optimal land-to-labor ratio (x^*) for the laborer-cultivator. Given that the right-hand side of the expression is independent of B , it is evident that the land-to-labor ratio is constant for this class of producers.

Moving to self-cultivators, as $t = L = 0$ for this class of producers, the only choice variable is R . Where now $x = B/[v(1 - R)]$, totally differentiating Eq. (A.15) with respect to B yields

$$\rho x g''(x) \left[\frac{1}{v(1 - R)} + \frac{B}{v(1 - R)^2} \frac{\partial R^*}{\partial B} \right] + u''(R) \frac{\partial R^*}{\partial B} = 0, \quad (\text{A.17})$$

which can be rearranged as follows:

$$\frac{\partial R^*}{\partial B} = -\frac{\rho(x/v)g''(x)}{\rho x^2 g''(x) + (1 - R)u''(R)} < 0. \quad (\text{A.18})$$

From the above expression, then, it is evident that self-cultivators consume less leisure. As

$$\frac{\partial x^*}{\partial B} = \frac{1}{1-R} \left(\frac{1}{v} + x^* \frac{\partial R^*}{\partial B} \right) \quad (\text{A.19})$$

we can substitute in Eq. (A.18) as follows:

$$\frac{\partial x^*}{\partial B} = \frac{u''(R)}{v\rho x^2 g''(x) + v(1-R)u''(R)} > 0. \quad (\text{A.20})$$

Thus, the optimal land-to-labor ratio increases with B for the self-cultivator class.

Regarding the small capitalist class, as $t = 0$ for these agents, the decision variables are R and L . We then have two first-order conditions, which are Eq. (A.15) and

$$\frac{\partial U_M}{\partial L} = \rho g(x)[1 - s'(L)] - \rho g'(x)\{w/v + x[1 - s'(L)]\} = 0 \quad (\text{A.21})$$

where now $x = (B - wL)/\{v[1 - R - s(L) + L]\}$. Rearranging Eq. (A.21), we have:

$$\frac{g(x) - xg'(x)}{g'(x)} = \frac{(w/v)}{1 - s'(L)}, \quad (\text{A.22})$$

the solution to which can be written as $x = X(w/v, L)$. From the strict concavity of $g(x)$ it is clear that the left-hand side of Eq. (A.22) is increasing in x , which implies that $\partial X/\partial L > 0$. Now, substituting $x = X(w/v, L)$ into Eq. (A.15) and partially differentiating with respect to L , we have the following expression:

$$\rho X g''(X) \frac{\partial X}{\partial L} + u''(R) \frac{\partial R}{\partial L} = 0, \quad (\text{A.23})$$

which, as $\partial X/\partial L > 0$, implies that $\partial R/\partial L < 0$. Then, totally differentiating Eq. (A.21) with respect to B yields

$$-(g - xg')\rho s'' \frac{\partial L^*}{\partial B} - [w/v + x(1 - s')] \rho g'' \frac{\partial x^*}{\partial B} = 0. \quad (\text{A.24})$$

As

$$\frac{\partial x^*}{\partial B} = \frac{1}{vn} - \frac{w}{vn} \frac{\partial L^*}{\partial B} - \frac{x}{n} \left[-\frac{\partial R}{\partial L} + (1 - s') \right] \frac{\partial L^*}{\partial B} \quad (\text{A.25})$$

we can substitute this expression into Eq. (A.24) and rearrange to obtain the following:

$$\begin{aligned} & \left\{ - (g - xg')s'' + [w/v + x(1 - s')]g'' \left[\frac{w}{vn} + \frac{x}{n} \left(-\frac{\partial R}{\partial L} + 1 - s' \right) \right] \right\} \frac{\partial L^*}{\partial B} \\ & = \frac{[w/v + x(1 - s')]g''}{vn} < 0. \end{aligned} \quad (\text{A.26})$$

Consequently, $\partial L^*/\partial B > 0$ as $1 - s' > 0$, $\partial R/\partial L < 0$, and $xg' - g < 0$ due to the strict concavity of g . Lastly, totally differentiating Eq. (A.22) with respect to B , we have the following:

$$\frac{\partial}{\partial x} \left[\frac{g(x) - xg'(x)}{g'(x)} \right] \frac{\partial x^*}{\partial B} = \frac{w/v}{(1 - s')^2} s'' \frac{\partial L^*}{\partial B} > 0. \quad (\text{A.27})$$

Again, from the strict concavity of $g(x)$, we know that $[g(x) - xg'(x)]/g'(x)$ is strictly increasing in x , so it follows that $\partial x^*/\partial B > 0$ or that the land-to-labor ratio increases with B for the small capitalist class.

Turning, finally, to the large capitalist class, as $t = l = 0$, it is evident that $1 - R = s(L)$. Therefore, this class of producers has one effective decision variable, which we deem to be L . The first-order condition is then as follows:

$$\frac{\partial U_M}{\partial L} = \rho g(x) - \rho g'(x)(w/v + x) - s'(L)u'(R) = 0 \quad (\text{A.28})$$

where $R = 1 - s(L)$ and $x \equiv (B - wL)/vL$. Totally differentiating the above with respect to B and rearranging the expression yields

$$\frac{\partial L^*}{\partial B} = \frac{(w/v + x)\rho g''/vL}{(w/v + x)^2 \rho g''/L + s'^2 u'' - s'' u'}. \quad (\text{A.29})$$

Noting that $x = h/L$ and $vh + wL = B$, we can multiply the above expression through by w and again rearrange as follows:

$$w \frac{\partial L^*}{\partial B} = \frac{\rho g'' w L / B}{\rho g'' + (v^2 L^3 / B^2) (s'^2 u'' - s'' u')}. \quad (\text{A.30})$$

As $wL/B < 1$ we know that $0 < w \partial L^* / \partial B < 1$. Totally differentiating $x = (B - wL)/vL$ with respect to B obtains

$$\frac{\partial x^*}{\partial B} = \frac{B}{wvL^2} \left(\frac{wL}{B} - w \frac{\partial L^*}{\partial B} \right) \quad (\text{A.31})$$

and then substituting in Eq. (A.30), we have:

$$\frac{\partial x^*}{\partial B} = \frac{vL^2}{B^2} \left[\frac{s'^2 u'' - s'' u'}{\rho g'' + (v^2 L^3 / B^2) (s'^2 u'' - s'' u')} \right] > 0. \quad (\text{A.32})$$

Thus, for the large capitalist class of producers, the land-to-labor ratio increases in B as well. In conclusion, then, as the optimal land-to-labor ratio remains constant for the laborer-cultivator class and increases in B for all subsequent classes, it is evident that expected output per hectare, while constant for the laborer-cultivator class, is decreasing in B for all other classes (i.e. when $B \geq B_1$).

APPENDIX B

PYTHON CODE

""" *Land Distribution and Modern Agricultural Value Chains*

Classes

Agents : a class for the specification of agent attributes and behavior
Firm : a class for the specification of firm attributes and behavior
World : a class for the creation, coordination, and documentation of agents
GUI : a class for GUI set-up

Parameters

world_shape : tuple
 Shape of the rectangular grid
n_agents : int
 Number of agents
A : float
 Productivity parameter on Cobb–Douglas production function
b : float
 Parameter on first-order aspect of supervision function
c : float
 Parameter on second-order aspect of supervision function
D : float
 Parameter on sub-utility (of leisure) function
G : float
 Cost per unit of distance travelled for agroindustrial firm
H : float
 Total quantity of available land
KF : float
 Fixed costs for the agroindustrial firm
KM : float
 Fixed costs associated with modern value chain
KT : float
 Fixed costs associated with traditional value chain
PF : float
 Price for processed output
Phi : float
 Intercept of working capital function
PL : float
 Poverty line
P0 : float
 Proportion of landless agents
Theta : float
 Parameter on land owned in working capital function
firm_moves_first : bool
 True to select firm location only at setup, else false
logformat1 : str

```

    Header format for log file
    logfile1 : str
    Location of log file

```

Dependencies

```

numpy : http://numpy.scipy.org/
scipy : http://www.scipy.org/
gridworld : http://code.google.com/p/econpy/source/browse/trunk/abm/
choose : available upon request (hendersonhl@gmail.com)

"""

import numpy as np
from scipy.optimize import brentq, fminbound
from gridworld import RectangularGrid, Patch, GridWorld
from gridworld import GridWorldGUI, ask, Agent
import random
import choose as ch
params = dict(world_shape=(20,20), n_agents=100, A=5.0, b=0.30, c=0.01,
              D=0.10, G=0.50, H=66.0, KF=2.0, KM=2.0, KT=0.5, PF=3.5, Phi=0.0,
              PL=1.3, P0=0.33, Theta=1.0, firm_moves_first=True, logfile='output.csv',
              logformat='\n {0},{1},{2},{3},{4},{5},{6},{7},{8},{9},{10},{11},\
{12},{13},{14}')

```

```

class Agents(Agent):
    """A class for the specification of agent attributes and behavior.

```

Methods

```

    agent_move1 : determines class, sector, factor demands, and welfare
    agent_move2 : adjusts welfare measures for firm reneging

```

Notes

```

    The class inherits from Agent.

```

```

    """

```

```

def initialize(self):
    """Set miscellaneous initial values."""
    self.U = 1.0 # Initial value is arbitrary
    N0 = int(params['n_agents']*params['P0']) # Number of landless
    self.N1 = N1 = params['n_agents'] - N0 # Number of landed

def agent_move1(self, w, v, Delta, Rho, growers):
    """Determine class, sector, factor demands, and welfare.

```

Parameters

```

w : float
    Price of labor
v : float
    Price of land
Delta : float
    Shape parameter for the land distribution
Rho : float
    Price premium for modern sector output
growers : list
    Locations of agents under contract

"""

```



```

A = params['A']
b = params['b']
c = params['c']
D = params['D']
H = params['H']
KM = params['KM']
KT = params['KT']
Phi = params['Phi']
PL = params['PL']
Theta = params['Theta']
p = self.p
if p == 0:      # Agent is landless
    self.hbar = hbar = 0
else:          # Agent is landed
    pprime = p - 1/float(self.N1)
    self.hbar = hbar = H*((1-pprime)**Delta - (1-p)**Delta)
self.uc = uc = self.position in growers # True if under contract
self.agent_class, self.sector, self.R, self.t, self.l, \
    self.L, self.h, self.q, self.Y, self.z, self.lmda, self.U = \
    ch.choose(A,b,c,D,hbar,KM,KT,Phi,PL,Rho,Theta,v,w,uc)

def agent_move2(self, w, v):
    """Adjust welfare measures for reneged upon agents and display.

    Parameters
    -----
    w : float
        Price of labor
    v : float
        Price of land

    """
    A = params['A']
    D = params['D']
    KM = params['KM']
    PL = params['PL']
    hbar = self.hbar
    R = self.R
    t = self.t
    l = self.l
    L = self.L
    h = self.h
    firms = self._world.get_agents(Firm)
    renege = [firm.renege for firm in firms][0]
    if self.position in renege:
        self.sector = 1
        self.q = q = A*h**(0.5)*(1 + L)**(0.5)
        self.Y = Y = q - w*(L - t) - v*(h - hbar) - KM
        self.z = Y < PL
        self.U = Y + D*R**(0.5)
    if self.sector == 0:      # HTML colors
        fillcolor = '#FFFFFF' # White
    elif self.sector == 1:
        fillcolor = '#4169E1' # Royal blue
    else:
        fillcolor = '#800000' # Maroon
    self.display(fillcolor=fillcolor, shape='square',
        shapsize=((hbar + 0.01)**(1/6.0), (hbar + 0.01)**(1/6.0)))

class Firm(Agent):
    """A class for the specification of firm attributes and behavior.

```

Methods

firm_move1 : determines optimal price premium and agents contracted
firm_move2 : determines quantity contracted, profit, and rejected agents
firm_neg_objective : the firm's (negated) objective function

Notes

The class inherits from Agent.

```
"""
def initialize(self):
    """Set miscellaneous initial values."""
    self.Pi = 295.0

def firm_move1(self, w, v, position):
    """Determine optimal price premium, agents contracted, and profit.
```

Parameters

w : float
 Price of labor
v : float
 Price of land
position : tuple
 The firm's position

```
"""
    results = fminbound(self.firm_neg_obj, 1+1e-03, 100.0,
        args=(w, v, position), xtol=1e-08, full_output=True, disp=0)
    self.Rho = results[0]
    self.EPi = - results[1] # Expected profit
    agents = self._world.get_agents(Agents)
    self.growers = [agent.position for agent in agents if
        agent.sector==2]

def firm_move2(self):
    """Determine quantity contracted, profit, and rejected growers."""
    G = params['G']
    KF = params['KF']
    PF = params['PF']
    Rho = self.Rho
    position = self.position
    agents = self._world.get_agents(Agents)
    templ = [(agent.q, agent.position) for agent in agents if
        agent.sector==2]
    temp2 = []
    temp3 = []
    temp4 = []
    for i in templ:
        F = np.sqrt((position[0] - i[1][0])**2 + (position[1] -
            i[1][1])**2)
        pi = PF*i[0] - i[0]*Rho - G*F # KF already incurred
        if pi > 0: # Adhere to contract
            temp2.append(i[0])
            temp3.append(F)
        else: # Renege
            temp4.append(i[1])
    NF = len(templ) # Number initially contracted
    F = sum(temp3)
    self.QF = QF = sum(temp2)
    self.Pi = PF*QF - QF*Rho - G*F - NF*KF
```

```

        self.renege = temp4

def firm_neg_obj(self, Rho, w, v, position):
    """Return firm's (negated) objective function.

    Parameters
    -----
    Rho : float
        Modern sector price premium
    w : float
        Price of labor
    v : float
        Price of land
    position : tuple
        The firm's position

    """
    G = params['G']
    KF = params['KF']
    PF = params['PF']
    Delta = self._world.Delta
    agents = self._world.get_agents(Agents)
    all_pos = [agent.position for agent in agents]
    ask(agents, 'agent_move1', w, v, Delta, Rho, all_pos)
    agents = self._world.get_agents(Agents)
    QF = sum(agent.q for agent in agents if agent.sector==2)
    NF = [agent.sector for agent in agents].count(2)
    growers = [agent.position for agent in agents if agent.sector==2]
    temp = []
    for i in growers:
        temp.append(np.sqrt((position[0] - i[0])**2 + (position[1] -
            i[1])**2))
    F = sum(temp) # Distance to contracted
    return -(PF*QF - QF*Rho - G*F - NF*KF)

class World(GridWorld):
    """A class for the creation, coordination, and documentation of agents.

    Methods
    -----
    setup : calls setup_agents and sets up log file
    setup_agents : creates agents and firm
    header2logfile : adds header to the log files
    log2logfile : logs data from the simulation
    schedule : applies move functions to the agents
    labor_market : returns the excess supply of labor
    land_market : returns the excess supply of land

    Notes
    -----
    The class inherits GridWorld.

    """
    def initialize(self):
        """Set miscellaneous initial values."""
        self.Delta = 0.10
        self.w = 0.05
        self.v = 1.60

    def setup(self):
        """Call setup_agents and set up log file."""
        self.setup_agents()

```

```

self.header2logfile()

def setup_agents(self):
    """Create agents and firm."""
    n_agents = params['n_agents']
    N0 = int(n_agents*params['P0']) # Number of landless
    N1 = n_agents - N0 # Number of landed
    locs = zip(np.tile(range(20),20), np.repeat(range(20),20))
    farm_locs = [] # Start agent setup
    for i in range(n_agents): # Place agents randomly
        loc = random.choice(locs)
        locs.remove(loc) # Draw without replacement
        farm_locs.append(loc)
    self.farm_locs = farm_locs = set(farm_locs)
    agents = self.create_agents(Agents, number=n_agents,
        locations=farm_locs)
    for i in range(n_agents): # Assign p
        if i < N0:
            agents[i].p = 0
        else:
            agents[i].p = (i + 1 - N0)/float(N1)
            agents[i].display(fillcolor='white', shape='square',
                shapexsize=(agents[i].p + 0.2, agents[i].p + 0.2))
    firm = self.create_agents(Firm, number=1) # Start firm setup firm
    if params['firm_moves_first'] == True:
        firm_locs = {} # Create dictionary
        w = brentq(self.labor_market, 1e-04, 10, args=(1.0, []))
        v = brentq(self.land_market, 1e-04, 10, args=(1.0, []))
        for i in range(100): # Firm has 100 candidate locations
            loc = random.choice(locs)
            locs.remove(loc) # Draw without replacement
            ask(self.get_agents(Firm), 'firm_move1', w, v, loc)
            firms = self.get_agents(Firm)
            firm_locs[loc] = [firm.EPi for firm in firms][0]
        self.firm_locs = firm.position = max(firm_locs,
            key=firm_locs.get)
        firm.display(fillcolor='black', shape='square', shapexsize=(1,1))

def header2logfile(self):
    """Add a header to the log file."""
    with open(params['logfile'], 'w') as fout:
        fout.write('Delta, w, v, LC, SC, SM, LG, Q, Z, W, pm, Rho, pc,\
            QF, Pi')

def log2logfile(self):
    """Log data from the simulation."""
    n_agents = params['n_agents']
    agents = self.get_agents(Agents)
    firms = self.get_agents(Firm)
    Delta = self.Delta
    w = self.w
    v = self.v
    H = sum(agent.hbar for agent in agents)
    LC = sum(agent.h for agent in agents if agent.agent_class==1)/H
    SC = sum(agent.h for agent in agents if agent.agent_class==2)/H
    SM = sum(agent.h for agent in agents if agent.agent_class==3)/H
    LG = max(1-LC-SC-SM, 0)
    Q = sum(agent.q for agent in agents)
    Z = sum(agent.z for agent in agents)/float(n_agents)
    W = sum(agent.U for agent in agents)
    pm = [agent.sector for agent in agents].count(2)/float(n_agents)
    Rho = [firm.Rho for firm in firms][0]

```

```

pc = len([firm.growers for firm in firms][0])/float(n_agents)
QF = sum(agent.q for agent in agents if agent.sector==2)
Pi = [firm.Pi for firm in firms][0]
with open(params['logfile'], 'a') as fout:
    fout.write(params['logformat'].format(Delta, w, v, LC, SC,
    SM, LG, Q, Z, W, pm, Rho, pc, QF, Pi))

def schedule(self):
    """Apply move functions to the agents."""
    self.w = brentq(self.labor_market, 1e-04, 10, args=(1.0, []))
    self.v = brentq(self.land_market, 1e-04, 10, args=(1.0, []))
    if params['firm_moves_first'] == False:
        firm_locs = {}
        locs = self.random_locations(100, exclude=True)
        for i in locs:
            ask(self.get_agents(Firm), 'firm_move1', self.w, self.v, i)
            firms = self.get_agents(Firm)
            firm_locs[i] = [firm.EPi for firm in firms][0]
        self.firm_locs = firm.position = max(firm_locs,
            key=firm_locs.get)
        firm.display(fillcolor='black', shape='square', shapsize=(1,1))
    ask(self.get_agents(Firm), 'firm_move1', self.w, self.v,
        self.firm_locs)
    firms = self.get_agents(Firm)
    Rho = [firm.Rho for firm in firms][0]
    growers = [firm.growers for firm in firms][0]
    self.w = brentq(self.labor_market, 1e-04, 10, args=(Rho, growers))
    self.v = brentq(self.land_market, 1e-04, 10, args=(Rho, growers))
    ask(self.get_agents(Agents), 'agent_move1', self.w, self.v,
        self.Delta, Rho, growers)
    ask(self.get_agents(Firm), 'firm_move2')
    ask(self.get_agents(Agents), 'agent_move2', self.w, self.v)
    self.log2logfile()
    if self.Delta >= 0.99:
        self.stop()
    self.Delta += 0.01

def labor_market(self, w, Rho, growers):
    """Return the excess supply of labor.

    Parameters
    -----
    w : float
        The current wage
    Rho : float
        Modern sector price premium
    growers : list
        Locations of agents under contract

    """
    Delta = self.Delta
    v = self.v
    ask(self.get_agents(Agents), 'agent_move1', w, v, Delta, Rho,
        growers)
    agents = self.get_agents(Agents)
    supply = sum(agent.t for agent in agents)
    demand = sum(agent.L for agent in agents)
    return supply - demand

def land_market(self, v, Rho, growers):
    """Return the excess supply of land.

```

```

Parameters


---


v : float
    The current land rental price
Rho : float
    Modern sector price premium
growers : list
    List of locations of agents under contract

"""
Delta = self.Delta
w = self.w
ask(self.get_agents(Agents), 'agent_move1', w, v, Delta, Rho,
    growers)
agents = self.get_agents(Agents)
supply = sum(agent.hbar for agent in agents)
demand = sum(agent.h for agent in agents)
return supply - demand

class GUI(GridWorldGUI):
    def gui(self):
        """Display buttons and plots."""
        self.add_button('Set Up', 'setup')
        self.add_button('Run', 'run')
        self.add_button('Stop', 'stop')
        def get_pi():
            firms = self.subject.get_agents(Firm)
            return [firm.Pi for firm in firms][0]
        self.add_plot('Firm Profit', get_pi)
        def get_welfare():
            agents = self.subject.get_agents(Agents)
            return sum(agent.U for agent in agents)
        self.add_plot('Agent Welfare', get_welfare)

if __name__ == '__main__':    # Setup and run the simulation
    myworld = World(topology=RectangularGrid(shape=params['world_shape']))
    myobserver = GUI(myworld)
    myobserver.mainloop()    # Keep GUI open after "run" completes

```

"""Post-simulation Graph Creation

Dependencies

```
numpy : http://numpy.scipy.org/
matplotlib : http://matplotlib.sourceforge.net/
signal_smooth : http://www.scipy.org/Cookbook/SignalSmooth
```

"""

```
import numpy as np
import matplotlib.pyplot as plt
import matplotlib.font_manager
import signal_smooth as ss

# Import data
data = np.genfromtxt( """/output.csv""", delimiter = ',', names = True)

# Extract data
sa_Delta = data[['Delta']]
sa_w = data[['w']]
sa_v = data[['v']]
sa_LC = data[['LC']]
sa_SC = data[['SC']]
sa_SM = data[['SM']]
sa_LG = data[['LG']]
sa_Q = data[['Q']]
sa_Z = data[['Z']]
sa_W = data[['W']]
sa_pm = data[['pm']]
sa_Rho = data[['Rho']]
sa_pc = data[['pc']]
sa_QF = data[['QF']]
sa_Pi = data[['Pi']]

# Copy the structured array into an array and smooth data when necessary
Delta = sa_Delta.view((float, 1))
w = sa_w.view((float, 1))
v = sa_v.view((float, 1))
LC = ss.smooth(sa_LC.view((float, 1)), window_len=55)
SC = ss.smooth(sa_SC.view((float, 1)), window_len=55)
SM = ss.smooth(sa_SM.view((float, 1)), window_len=55)
LG = ss.smooth(sa_LG.view((float, 1)), window_len=55)
Q = ss.smooth(sa_Q.view((float, 1)), window_len=55)
Z = ss.smooth(sa_Z.view((float, 1)), window_len=55)
W = ss.smooth(sa_W.view((float, 1)), window_len=55)
pm = ss.smooth(sa_pm.view((float, 1)), window_len=55)
Rho = ss.smooth(sa_Rho.view((float, 1)), window_len=55)
pc = ss.smooth(sa_pc.view((float, 1)), window_len=55)
QF = ss.smooth(sa_QF.view((float, 1)), window_len=55)
Pi = ss.smooth(sa_Pi.view((float, 1)), window_len=55)

# Set-up
fig = plt.figure()
fig.subplots_adjust(left=None, bottom=None, right=None, top=None,
                    wspace=0.35, hspace=0.35)
matplotlib.rcParams['font.size'] = 14.0
matplotlib.rc('xtick', labelsiz=11)
matplotlib.rc('ytick', labelsiz=11)

# Agent welfare, output, poverty, and proportion modern
ax2 = fig.add_subplot(121)
```

```

ax3 = ax2.twinx()
plot5 = ax2.plot(Delta, W, 'k-', label='W')
plot6 = ax2.plot(Delta, Q, 'k—', label='Q')
plot7 = ax3.plot(Delta, Z, 'k:', label='Poverty')
plot8 = ax3.plot(Delta, pm, '0.55', label='pm')
ax2.set_xlabel('$\delta$')
ax2.set_ylim(ymin=0, ymax=650)
ax2.set_title('(i) Agent Outcomes')
ax2.set_ylabel('$W$, $Q$')
ax3.set_ylabel('$Z$, $p_m$')
plt.legend([plot5, plot6, plot7, plot8], ['$W$', '$Q$', '$Z$', '$p_m$'], loc=5,
           bbox_to_anchor=(0.95, 0.5))

# Firm Rho, proportion contracted, output, and profit
ax5 = fig.add_subplot(122)
ax6 = ax5.twinx()
plot13 = ax5.plot(Delta, Rho, 'k-', label='Rho')
plot14 = ax5.plot(Delta, pc, 'k—', label='pc')
plot15 = ax6.plot(Delta, QF, 'k:', label='QF')
plot16 = ax6.plot(Delta, Pi, '0.55', label='Pi')
ax5.set_xlabel('$\delta$')
ax5.set_title('(ii) Firm Outcomes')
ax5.set_ylabel('$\rho$, $p_c$')
ax5.set_ylim(ymin=0, ymax=3.5)
ax6.set_ylabel('$Q_F$, $\Pi_F$')
ax6.set_ylim(ymin=0, ymax=800)
plt.legend([plot13, plot14, plot15, plot16],
           ['$\rho$', '$p_c$', '$Q_F$', '$\Pi_F$'],
           loc=5, bbox_to_anchor=(0.95, 0.5))
plt.show()

```


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