Land Reform and Technical Efficiency: theory and panel data evidence from Brazil

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Land reform settlements are increasing in many Brazilian regions, recent census data show that up to 13% of rural establishments in Brazil are derived from land reform programs. New Institutional Economics has provided inputs for market-assisted land reform based on land redistribution through endogenous institutions. Theory and prior evidence has said that the following features are determinants of production efficiency: the establishment of complete property rights, the owner-cultivator and the inverse relationship, peer monitoring in rural credit markets, and decentralization of governance with community-based self-selection of beneficiaries and land selection with bargaining. This framework is complemented with the fact that beneficiaries enter the program in singular situations and are prone to high individual heterogeneity and a diversity of institutional constraints. Using an empirical strategy based on Agricultural Economics' recognition of farmers' responsiveness to changing incentives in a dynamic world we estimate a production function model to uncover the beneficiaries' structure of production. Based on the recognition that systematic deviations from optimal production occur due to technical inefficiency, a stochastic frontier analysis with time-varying efficiency effects is employed. The model is performed for 204 households for the years 2000 and 2006 with a sampling procedure devised for an impact evaluation of the Programa Cédula da Terra, which solves the policy endogeneity problem. Results indicate that beneficiaries' success depend on a fine-tuning of a set of variables in a very rigid and restrictive environmental and institutional setting. The model uncovered that the product is determined by a structure of endogenous variables but that the trajectory of technical efficiency is also determined by exogenous variables. A closer analysis of the households according to the level of technical efficiency revels also the possibility of the existence of poverty traps, which would be caused not only by the ex post production structure but also by self-selection due to subsistence requirements. The results indicate therefore that technical efficiency of households participating in market-based land reform policies and the refinement of the policy's targeting process are certainly open issues.

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Keywords: land reform; endogenous institutions; production efficiency; stochastic frontier analysis

JEL: D23; D24; Q12; Q15

I. Introduction

In the wake of four democratic governments, land reform settlements are increasing in many Brazilian regions. According to IBGE (2009) census data, which is intended to be current up to 2005–2006, approximately thirteen per cent of all rural establishments in Brazil are land reform settlements. By design, land reform settlements actively participate in social programs that aim at enhancing peasant-family production dynamics; such as school meal, food acquisition, credit access through the National Program of Strengthening of Family Farms (*Programa Nacional de Fortalecimento da Agricultura Familiar* or PRONAF), technical assistance, and other similar programs, related to bioenergy, for example. Policies adopted by the agrarian development leadership in Brazil show a consistent focus on transforming these settlements into sustainable organizations by means of market integration and increasing productivity, so that they can become economically viable and thus emancipated.

The issue of access to agricultural land in developing countries can be considered a secular quest in politics and economics, as de Janvry *et al.* (2001) assert, "the problem of optimum access to farm land, *i.e.*, access for whom and under what conditions, remains a serious unresolved issue, frequently with high efficiency and welfare costs, environmental consequences, and explosive political manifestations". Specifically in Brazil, where land concentration is high and persistent[1], all inequality-related costs and consequences are present in the socio-economic system.

Land reform policy in Brazil is performed by two complementary mechanisms of land access. The first refers to the expropriation of rural properties and is the main

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[1] Brazil's land concentration Gini coefficient remains stable from 1975 to 2006, at approximately 0.85 (Hoffmann and Ney 2010).

policy of agrarian reform in Brazil, and is often referred as state-led land reform. The second refers to market-assisted land reform, which is considered a policy tool, complementary to state-led redistribution. This article deals only with the pilot program of market-assisted land reform in Brazil, named *Programa Cédula da Terra* (PCT), which started operation in 1998 funded by the World Bank, benefiting fifteen thousand families at a total cost of $150 million USD.

This program is a policy based on years of economic research, standing on prior theory and evidence alike. Basically, it works by means of decentralized intervention in the land and credit markets, providing credit to groups of landless farmers, to negotiate and acquire in associations their own properties.

The beneficiaries are empowered to make decisions on the use of funding resources, the strategy of distributing lots among the families, and the use of individual parcels and common lands. The federal government coordinates PCT providing the credit and assuming the risk. The land is acquired by a credit transaction with the federal government, which pays the landowner on the transaction, with payment terms of twenty years, and minimum grace period of three years, providing extension depending on regional environmental conditions. State government guarantees settlers' property rights, technical assistance for productive projects, and community investments for public goods. And local governments coordinate the formation of associations to interact with rural workers unions and other spheres of government.

Both the agrarian political leadership in Brazil and World Bank underlying economic rationality thus expect the constitution of efficient projects where settlers can generate agricultural surplus, as well as productive superiority in relation to state-led settlements. However, rigorous analysis of the impact of land reform policies is sparse in Brazil and worldwide[2].

Some authors claim that market-assisted land reform cause only negative impacts (Borras, 2003; Pereira, 2006). However, these authors base their analysis on arbitrary relations and data selection that do not rely on rigorous scientific methods and thus raise the risk of data misinterpretation.

For the best of our knowledge only two studies deal specifically with the efficiency effects of market-assisted land reform. Magalhães *et al.* (2011, 2012) both develop a stochastic frontier model with technical efficiency effects to analyze beneficiaries' agricultural production.

Magalhães *et al.* (2012) compares technical efficiency of beneficiaries of state-led and market-assisted land reform programs (PCT) in a cross-section model for the year 2000, based on the hypothesis that the establishment of full property rights to land would result in initially superior technical efficiency. That was not confirmed, because beneficiaries face similar internal and external restrictions. Diminishing returns to scale on production revealed a strategy of farming based on partial use of available land and low intensity of labor and capital usage. Land was the factor that most contributed to growth in production and farmers near the stochastic efficiency frontier have more intensive production systems: higher levels of production, variable inputs, collective labor, livestock, use of machinery, with cultivation in lowland and irrigated areas.

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[2] See, for example, Ghatak and Roy (2007) for a review of evidence for India, Otsuka (1991) and Otsuka, Lordova and David (1992) for evidence on Asia, and Deininger (1999) for evidence on the initial experience with market-assisted land reform in Colombia, Brazil, and South Africa. See also Lipton (2009) for an excellent review of land reform throughout the world.

Magalhães *et al.* (2011) did a study based on PCT five years after installation, in a cross-section model for the year 2003. The authors find that in the short-run household production depends mainly on intensive use of labor, while land and variable inputs effects on technical efficiency are absent and beneficiaries face credit restriction to perform productive investments. The resources available at initial installation had not matured five years later, and thus the current traditional production adopted by settlers in the region is still working as before. Those systems are based on a set of mixed cultures and rotation with animal breeding, mostly for self-consumption as a major goal. The climatic and soil conditions in many areas are not suitable for farming, but there is exploitation of smaller areas, such as meadows, which tend to receive higher intensity of use, thus land is not determinant for growth in technical efficiency in the short term, but will be determinant for the expansion of production in the future.

Advancing from these studies, we expose PCT's economic rationality, complementing the underlying basic theoretical framework with the fact that households participating in this policy are characterized by high individual unobserved heterogeneity and may suffer from a diversity of institutional constraints not treated by this policy, thereby limiting the impact of a redistribution of complete property rights. In sequence a stochastic frontier model is applied to a unique panel data set of beneficiaries. The theoretical framework is expected to shed light on the singular conditions under which households enter this land reform program, while panel data can assure the observation of the policy effects through time and a better econometric identification and specification, thus improving the model's explanatory power, and reliability of the policy recommendations.

In the next sections we introduce our theoretical framework (II), the empirical strategy (III), the results from the econometric estimation and a frontier analysis of the technical efficiency index (IV), a discussion of the results with policy recommendations (V), and the concluding remarks (VI).

II. Access to Land and Efficiency

A. Redistribution Through Endogenous Institutions

There is widespread support for reforming agricultural property rights and growing consensus on how to do it (see, for example, Binswanger, Bourguignon and van den Brink, 2009). There is, however, much less consensus on the efficiency effects of policies that seek to reform rural property rights due to the lack of research in the area. Banerjee, Gertler and Ghatak (2002) argue that "part of the reason [for the lack of research] is that there are few examples of large-scale changes in property rights that were not accompanied by major social unrest. Moreover, analysing the impact on efficiency is difficult because of data limitations and the fact that the structure of property rights is itself endogenous."

The endogeneity of the structure of property rights steams from the fact that as an institution it is compromised by many agents which decisions are bounded by formal rules and informal norms, and at the same time the results of these decisions affect the very rules and norms that bound the decisions. Hence, the redistribution of land is here said to be through endogenous institutions because beneficiaries have decisive participation in the construction of the redistributed property rights and the underlying structure. Important parameters such as effort, investment, land use, collective activities, and so on, are endogenously and continuously adjusted by informal norms or endogenous contracts rather then exogenously imposed.

Thereby rendering an exogenous variable correlated with the institution of property rights and which is not correlated with agricultural production becomes tricky. It is hard to say how much of the production was caused by the structure of property rights itself. Banerjee, Gertler and Ghatak (2002), as solution to this problem, explore a within-state variation of land reform implementation in India (Operation Barga) to identify the effects on agricultural productivity, while relating these results to endogenous parameters of the policy structure (that is, technology and production organization) that are theoretically related to production efficiency. In our case we solve the endogeneity problem by using a data set that has a quasi-experimental design devised for an impact evaluation of PCT, thereby with randomization properties that can yield results attributed to effects within the policy environment.

While Operation Barga has only one dimension of reform, that is reforming tenancy relations, PCT can be considered multidimensional, in virtue of dealing with more issues in addition to property rights, therefore our analysis does not evaluate only the institution of property rights. In addition to land tenure and property rights within an owner-cultivator framework, PCT gives rise to peer monitoring in rural credit markets, community-based selection of beneficiaries, and bargaining in the land market. The junction of these elements would constitute a structure of decentralized governance supported by social capital and community governance, lessening political control, and hence increasing efficiency (Bowles and Gintis, 2003; Buainain, Silveira and Magalhães, 1999; Gordillo, de Janvry and Sadoulet, 1998). How these issues affect production is the object of detailed analysis presented ahead.

A1. Land tenure and property rights

Land is a fundamental asset for the poor. Securing legal ownership of land is suggested to have two basic effects: (1) to increase incentives and ability to invest, due to a lower perceived risk in the appropriation of future income streams and (2) a favourable access to institutional credit using land as collateral[3] (Feder, 1987). In addition, a system of land tenure can improve the functioning of land markets by facilitating efficiency-enhancing transfers (Deininger, 1999). Fluidity of land transactions create deals where land size approximates optimal size for family farming, allocate unused land within the settlement–thus supporting the expansion of successful beneficiaries while permitting the unsuccessful to exit–, and avoid adverse selection of low quality land.

It is recognized that property rights do not need to be individual titles, as long as the recipient community can cooperate in managing the resource for the common good (Platteau, 2000; Deininger and Binswanger, 1999). However, they need to be 'complete property rights'. Ostrom (1990) defines completeness to include the rights to access, extract, manage, exclude others, and alienate (that is, sell). PCT distributes titles that are comparable to the description of complete property rights that are said to be superior to those redistributed by previous reforms, where "rights were typically usufruct with state ownership, or common property resources with community jurisdiction while very few received titles" (de Janvry and Sadoulet, 2011).

Thus, in Northeast Brazil where complete property rights does not dominate, PCT could, therefore, raise production efficiency by increasing household's ability to produce marketable surplus by enhancing their social and economic status thus their ability to self-insure and to access financial markets, while also providing incentives to exert non-contractible effort, make investments, and use natural resources in a sustainable manner.

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[3] The improvement of property rights to facilitate the use of fixed assets as collateral is popularly known as the "de Soto effect", in reference to the policy advocate Hernando de Soto.

A2. Owner-cultivator and the inverse relationship

Heretofore, property rights influence the organization of agriculture. The mode in which the owner is also in control of production is said to be superior to tenancy arrangements (such as sharecropping) and to very large-scale agriculture because there are weak economies of scale in agricultural production, thus optimal farm size approximates the scale that family labour is fully allocated. In addition, smallholder production reduces misuse of natural resources and workers increase labour effort due to residual claimancy of profits. This fact put in broad perspective is usually referred as the 'inverse relationship' of land size in relation to productivity, and this fact alone used to be the main economic rationality supporting large state-led land reform programs (Lipton, 2009; Deininger and Binswanger, 1999; Shaban, 1987; Ip and Stahl, 1978[4]).

An owner-cultivator is usually supported by family labour. When this is the case, the level of effort chosen is usually greater then if working for a wage due to household member's residual claimancy to profits. That is, they reap full returns from factors of production, and due to the fact that they share in the risk of the productive process (Deininger and Binswanger, 1999). Over and above, the inverse relationship framework suggests that larger farms are more difficult to monitor labour by reason of great spatial dispersion of production and constant variations in the natural environment, therefore inducing shirking if production is not done by family labour (Feder, 1985).

The superiority of the owner-cultivator farm in relation to farms with tenancy is important because PCT usually diverts labour force from tenancy arrangements.

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[4] Interestingly, Ip and Stahl (1978) already incorporate transaction costs, entrepreneurship and ability into their analysis, which we will see ahead.

[5] When interests rates can act as a screen which regulates risk composition of the loan portfolio

Changing the assignment of property rights–the beneficiary now an owner-cultivator–is expected to increase utilization of family labour and effort towards production.

Finally, other important characteristic of the owner-cultivator pertains to the choice of productive projects, which can be aligned more closely to the household's farming ability and agricultural experience.

A3. Peer monitoring in rural credit markets

Deininger and Binswanger (1999) argue that "the supervision cost advantage of small farmers could easily be overturned if they are either completely rationed out of credit markets or face higher credit costs" and thus, with their limited ability of coping with risk, face difficulties accessing the credit and insurance markets. Hence, government intervention in credit markets has been called for in rural regions where credit rationing[5] is the daily norm. However, cheap credit directly supplied by the government is not the answer. Viewed through the imperfect information paradigm, credit market failure is not caused by interest rates that are too high because they take into account risks of default (classical view) or lack of competition (monopolistic power view), but by credit rationing due to problems of screening, incentives, and enforcement. The screening problem is a consequence of the existence of different likelihoods of default among borrowers, the incentives problem arises when it is costly to ensure repayment, and the

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[5] When interests rates can act as a screen which regulates risk composition of the loan portfolio there may be credit rationing with no tendency of rising interests rates, because very high interests rates may select only very risky projects when there is imperfect information, thus supply does not clear the market. For example, in rural regions, periods of bad harvest are usually accompanied by lack of credit at any price, as non-resident lenders and institutions appear not to be able to form a sufficiently accurate judgment of households' ability to repay (Hoff and Stiglitz 1990).

enforcement problems exists because it is difficult to compel debt payoff.

In this sense, Hoff and Stiglitz (1990) state "screening, incentive, and enforcement problems in credit markets are often mitigated through interlinkages between the credit market and other markets, (for example, land and commodity markets). The creation of a dense network of market interactions, which we would expect as development proceeds, lowers screening and enforcement costs".

Accepting the imperfect information paradigm, PCT created an institution where the intervention in the credit market, by means of supplying credit for acquiring land, is done using indirect mechanisms[6]. That is, the interlinkage with the land market, as a way to reduce screening and enforcement costs, is complemented with incentives provided by the threat of exclusion from the PCT program and other federal government programs such as PRONAF, and the land title, as punishment for defaulting or leaving the project unannounced.

Additionally, a structure of peer monitoring is included. Peer monitoring is not just a way to increase effective collateral, but also an intricate incentive mechanism. Allowing borrowers to be cosigners of a loan is a way to use local knowledge in the

[6] Hoff and Stiglitz (1990) conceptually distinguish mechanisms for solving the three problems (screening, incentives, and monitoring) in direct and indirect mechanisms. The theory of indirect mechanisms rely on endogenous contracts where the borrower by responding in his best interest revels information to the lender about his riskiness and induces the borrower to take action to reduce the likelihood of default and timely repay the loan. Direct mechanisms rely on lender's resources for screening and enforcement, and vary according to geography, kinship, and type of crop and technology used. Other direct mechanisms are the trader-lender interlinkage, collateral requirements, usufruct loans, and rotating savings and credit associations.

presence of costly information that could give rise to efficiency and welfare-enhancing situations.

The mechanism design to achieve these favorable situations relies on homogeneity of agents and group formation by assortative matching, so the gains from improved monitoring are worth the cost of increased interdependence. By making repayment interdependent, demand-driven beneficiaries are led to match according to a assortative process. This process needs to ensure the equalization among beneficiaries of default probabilities, bringing about the possibility of matching intent and productive abilities as well.

A4. Community-based beneficiary selection and land selection with bargaining

The group selection required by the peer monitoring incentive mechanism is done at the community level by self-selection with neighbourhood effects. That is, a person decides to participate in the program based on individual choice, the influence of family and friends, or a mix of both factors. This demand-driven approach to land redistribution can arguably increase production efficiency by selecting “better beneficiaries” and “better assets” (Buainain, Silveira and Magalhães, 1999).

Ultimately, this is achieved through the decentralization of governance, which can avoid political capture by removing paternalist relations between the state and the landless, whereby decreasing political cycle interferences and increasing landless’ freedom of choice in both selection process and project of agricultural production.

Although decentralization can possibly increasing the extension of elite capture due to power asymmetries between landless and landowners, giving rise to the possibility of exploitation or collusion, these problems can be mitigated by the obligation of credit repayment by the beneficiaries, along with a grant for project's public goods and the introduction of a bargaining process for the land transaction[7].

The obligation of credit repayment, in addition to mitigating collusion, is also a strong incentive not to pursuit lands of low quality, which would not yield the necessary future stream of income to pay off the debt, and to pursuit underutilized lands, reducing the expected purchase price.

In addition, the government guarantees an amount for investments on public goods (for example, complementary and community-level infrastructure) that depend on the value paid for the land. A fixed amount grant is offered per family, the difference between this fixed amount and the value actually paid for the land is to be invested in public goods within the project without the corresponding debt obligation.

Including a decentralized beneficiary self-selection process, a bargaining process and debt repayment, PCT thus enhances the search for better beneficiaries, better lands, and increases communal investment without increasing debt obligations, paving the way for efficient production and economic viability.

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[7] This was likely designed in light of previous experience in Colombia, where market-assisted land reform policy gave grants amounts to 70% of the negotiated land price, which in turn was restricted for this purpose only and could not be used to undertake complementary investments, therefore creating incentives for collusion between sellers and buyers to overstate land prices so the grant could completely cover the land price, thus buyer and seller could divide the surplus. In addition, land selection was then biased towards the most developed agricultural land already endowed with infrastructure and complementary resources, thereby reducing the program to a transfer of assets rather then favoring the creation of new ones (Deininger 1999).

B. On the Impossibility of a "Complete Redistribution": institutional constraints and high individual heterogeneity

While land redistribution by reforming tenancy relations is dubbed as a "limited redistribution" of property rights (Banerjee, Gertler and Ghatak, 2002), policies alike PCT aim at a "complete redistribution" because it distributes full ownership of the property rights, which would provide efficient production due to the reasons mentioned in section A. As elaborate as PCT is, there are some other factors that need to be taken in account to understand beneficiaries' production structure and PCT's efficiency effects as a way of land access.

Considering the fact that rural households in many parts of the developing world face large, uninsured variations in income streams (Carter and Lybbert, 2012) two questions become central: will the less well-off be able to defend its productive asset base, despite the stylized fact of small holders' superior competitiveness in the use of these assets, and furthermore, will other institutions, PCT aside, support the productive use of these assets?

B1. Human capital, ability, and learning

PCT beneficiaries have very low levels of income, thus any level of human capital (that is, formal schooling and accumulated experience) would have an impact in production efficiency, by means of increasing absorptive capacity and the level of general knowledge and information. It is consensus that the levels of formal schooling in Northeast Brazil are very low, thus accumulated experience and technical assistance have great importance, becoming indispensable tools for efficient production. Yet, Buainain, Silveira and Magalhães (1999) demonstrate that technical assistance was frequently of very poor quality or inexistent in the initial phase of most projects, which certainly increases probability of failure.

Low levels of human capital and failure of technical assistance would put more emphasis on the manifestation of accumulated experience in ability towards farming and the matching of these abilities with planned activities. Assunção and Ghatak (2003) argue that ability often remain as unobserved heterogeneity in studies quantifying smallholder productivity, thus it could be an influence in producing the inverse relationship. Thus the existence of a complete redistribution of property rights is linked to a self-selection process that maximizes the demand for land of farmers with more ability in both production and entrepreneurship. However, the beneficiaries' selection process did not target ability, thus this characteristic remains as unobserved individual heterogeneity.

Furthermore, learning in agriculture has also been recognized as of utmost importance in the process of agricultural development with diffusion and adoption of new technologies (Foster and Rosenzweig, 1995; Vieira-Filho and Silveira, 2012)[8]. Nevertheless, at a loss in efficiency, PCT does not integrated the necessity of new technology adoption, but allows for some time-related learning to take place, since the debt repayment is not immediately due plus the fact that agriculture is a continuous process with strong neighbourhood effects and learning spillovers.

B2. Assets and Wealth Inequality

Alike the Colombian reform (Deininger, 1999), the Brazilian program was shown to select individuals with low level of assets (Souza Filho *et al.*, 2001). Observation of reality makes one challenge the natural assumption that at the subsistence level well-

[8] Otsuka (1991) conditions the success of land reform in the Philippines to the adoption of new technology. Bardhan and Mookerjee (2011) recently reaffirm this view, stating that the success of tenancy reform in India is correlated to the adoption of green revolution kits.

being would not vary much. Elbers *et al.* (2004) discards this "natural assumption" and argue that theory and evidence support that local inequality may also affect local development outcomes and such information has rarely made its way into program design.

As put by Zimmerman and Carter (2003), the ability to maintain a productive asset base speaks directly to the design and feasibility of market-assisted land reform programs. The level of wealth, as measured by the ownership of assets, is a fundamental variable related to the composition and profitability of agricultural investment, and thus the choice of a low-risk low-return or a more risky with high-return strategy is directly dependent on the level of assets (Rosenzweig and Binswanger, 1993). Furthermore, Rosenzweig and Binswanger (1993) argue that in the presence of risk, such as weather risk as is the case of much of low-income agriculture, the effect of wealth inequality on production increases because farmers select portfolios of assets that are less sensitive to rainfall variation an thus less profitable, therefore the loss in efficiency associated with risk mitigation is considerably higher among the poorer farmers[9]. In addition, investment portfolios of small farmers also reflect their difficulties in smoothing consumption in face of high risks. Dercon (1998) states a similar point, where evidence suggests that households with lower endowments are less likely to own cattle (an asset), which is usually a profitable activity but requires lumpy investments and are a liquid

[9] Banerjee *et al.* (2001) sustains a related point but from a different angle of analysis. The authors argue that within farmer cooperatives (which is the case of PCT) inequality of asset ownership affects relative control rights of different groups of members. Increased local heterogeneity (of landholdings in the case) causes increased inefficiency by inducing a lower price of members' inputs and lower level of installed crushing capacity (of sugarcane).

asset for smoothing consumption, thus households resort to low-risk low-return activities.

However, the nonseparability between current consumption and future productive capacity in the form of subsistence requirements leads to a co-existence of consumption smoothing and asset smoothing[10] (Carter and Lybbert, 2012; Zimmerman and Carter, 2003). Asset-based risk coping thus results in positive correlation between initial wealth and portfolio rate of return (Zimmerman and Carter, 2003)[11]. Furthermore, Santos and Barrett (2011) argue that persistent poverty excludes people, in addition to formal credit channels, also from informal credit networks. Persistent poverty would in turn dampen social capital, compromising the establishment of governance and the functioning of the incentive mechanisms.

B3. Governance and Institutions

Evidence from the bargaining processes, based on Silveira *et al.* (2000), has assured the success of its workings in establishing a lower bandwidth for the land price than the traditional policy. There is, however, less evidence that this process led to the permanent selection of plots of higher quality and of underused productive farms in relation to traditional policy. While, on the other hand, there is not evidence that only

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[10] Instead of using assets or savings to smooth consumption, the strategy of asset smoothing varies consumption to buffer assets. According to Carter and Lybbert (2012) "despite solid theoretical foundations for the notion that poor, borrowing-constrained households will inter-temporally manage assets to smooth consumption, the consumption smoothing hypothesis has not always withstood empirical scrutiny".

[11] In this sense, Santos and Barrett (2006) results underscore that it is critical to protect assets against exogenous shocks and the importance of incorporating indicators of ability in the targeting of asset transfers, because households above an estimated optimal accumulation bifurcation threshold, according to Carter and Lybbert (2012), can completely insulate their consumption from weather shocks.

low quality and degraded lands were chosen, there was a high degree of impatience and the meddling of political forces in what should have been a decentralized community-based selection. Fact that could be at the root of the lack superior plot dominance, which in turn could hamper the policy's efficiency goals.

Likewise, evidence from the processes of beneficiary selection, based on Souza Filho *et al.* (2001) has assured the success in selecting the targeted population. It is not possible to say, however, that a demand-driven process was enough to ensure the selection of a majority of beneficiaries with entrepreneurial spirit for agricultural activities or even the selection of those with the most knowledge on the subject. Since this process did not rule out political meddling as well, the community-based formation of groups/associations was compromised, also hampering efficiency goals[12]. That is because for the structure of governance's incentives to work groups need to be formed on the base of assortative matching, not only because of default probabilities, but also to match intent and productivity goals, and thus regulate group size and land selection accordingly[13]. It is not necessary, however, that group formation precedes land selection, since it is recognized that land markets are highly incomplete in Northeastern Brazil. If groups are formed after land selection it is necessary then that this formation reflects the endowments of the property and of the region. PCT allowed for attrition,

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[12] According to Buainain, Silveira and Magalhães (1999) 52 per cent of associations chose fist-best property with little evaluation of negotiation.

[13] Indeed, Deiniger (1999) argues that in Colombia groups were often based on coincidence more then on similarity of interest, with inexistent capacity to solve conflicts and devise effective strategies for common goals. "Unless beneficiaries have a clear idea of productive opportunities consistent with their abilities *before* they formulate productive projects that for the basis for 'shopping' for land, it is very difficult to break this deadlock" (Deininger 1999, original emphasis).

which helps minimize problems caused by previous incomplete matching between beneficiaries and between the beneficiaries and the chosen property.

It is recognized in the literature that groups of smaller size are more effective in establishing thrust and hence the formation of social capital (Bowles and Gintis, 2003). Within group cooperation and establishment of effective management is thus the key to enhance completeness of the redistributed property rights and to rebuff the cost of increased interdependence caused by the mechanism of peer monitoring. Additionally, commons cooperation is extremely important to achieve the scale required by the mechanization of agriculture. The lack of scale and mechanization is recognized as one of the principal barriers to farm profitability (Foster and Rosenzweig, 2010). The ability to cooperate in the management of common access areas will then determine the rate of allocation of land under dual individual-collective use, affecting household resource allocation, including labour (McCarthy, de Janvry and Sadoulet, 1998).

In this sense, social capital can be established by economic rationality on the basis of economic calculativeness, which in turn would be the underlying process for the formation of thrust (Williamson, 1993). In similar fashion, social capital can also be established based on evolving institutions affecting existing social norms and inducing the creation of new ones (Platteau, 2000)[14]. However, despite the establishment of thrust, social norms, and the decrease in perceived risk due to secure legal ownership of land, many uninsured risks can persist, affecting the process of decision-making leading

[14] Platteau (2000) mainly argues about evolutionary property rights in Africa and how the creation of property rights depends heavily on social norms. The author also stresses the role of population and road network density, which affects transaction costs and market structure, hence affecting social norms. Social norms towards more or less participation in markets can thus evolve and determine subsequent production decisions of a given community.

households to establish a low-risk low-return strategy with dependence on outer income (Deininger and Binswanger, 1999).

Against this effect, credit access during the startup phase is of utmost importance for the sustainability (in the monetary sense) of the settlement, and thus provide alternatives to the low-risk low-return strategy (Deininger, 1999). An important caveat on this matter is made in Carter and Olinto (2003), where the authors affirm that property rights reforms do not automatically work out the credit supply effect. Given high levels of wealth inequality, which in turn would lead to a pattern of wealth-biased liquidity constraints, property rights reform will get institutions "right" only for the wealthier producers – clearly not the case of land reform beneficiaries. In addition, Feder *et al.* (1990) points out that in a setting with credit-constrained rural households, long and medium-term formal credit is practically inexistent, and much of the expansion in the sort-term credit supply will be diverted to consumption.

III. Empirical Strategy

A. The stochastic frontier method applied to the measurement of inefficiency in agriculture

Consistent with our theoretical framework, the empirical analysis employed is based on the recognition of farmers' rational behaviour and responsiveness to changing incentives in a dynamic world, thus refuting the notion that farmers are poor because of cultural characteristics such as lack of work ethic, lack of an understanding of savings, or general ignorance on how to make use of their resources[15].

However, considering only an axiomatic choice theory as the underlying assumption, as in the 'poor but efficient' paradigm, poverty would arise from a

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[15] This assumption is one of Schultz's contributions to agricultural economics (Ball and Pounder 1996).

stationary equilibrium resulting from a low-risk production choice and low productivity of the available factors, which in turn is necessary but not sufficient to apply our theoretical framework. As put forth by section II, beneficiaries' achievement of high levels of efficiency depends on the fine-tuning of a set of variables in a very rigid and restrictive environmental and institutional setting. Furthermore, it is an accepted fact that in developing countries systematic deviations from optimal production occurs due to technical and allocative inefficiency (Shapiro 1983). Inefficiencies arise not only from the optimization process but also due to various constraints imposed by nature and institutions. To account, therefore, for permanent deviations from the optimal frontier we employ a stochastic frontier analysis.

A1. Presentation of the Method

The general notion of economic efficiency, which reflects the result of production of goods and services by means of a given amount of available resources, is passive of separation into technical and allocative efficiency. Technical efficiency can be defined as the maximum output that can be achieved from a specified level of inputs, given the set of technologies available to the producer. Allocative efficiency refers to the adjustment of inputs and outputs as a reflection of relative prices. Hence, economic efficiency illustrates the ability to combine inputs and outputs in optimal proportions in light of prevailing prices and available technologies.

Thereby, profit maximization requires production at the highest level given a certain level of inputs used (technical efficiency), using an appropriate combination of inputs in light of the relative prices of each input (allocative efficiency of inputs) and producing an appropriate set of products given the set of prices (allocative efficiency of products) (Coelli *et al.*, 2005).

The development of methods to estimate the relative technical efficiency among production units began with the definition by Farrell (1957). The information for estimating the production frontier is obtained from the ranges shown for a given data set, becoming the base reference to the relative positioning of the level of efficiency of each production unit.

This advance, made possible by identifying the stochastic frontier, proposed independently by Meeusen and van Den Broeck (1977) and Aigner, Lovell and Schmidt (1977), was the result of incorporating one term to capture inefficiency and other to identify measurement and specification errors, making the assumption of complete efficiency a flexible concept. This specialized method allows the comparison of productive efficiency among production units, at merely one point or between two or more points in time, using microdata. The model allows for studying both differential efficiency between production units and the random error without the need to assume that these units are operating at full technical efficiency.

The stochastic frontier production model can be specified according to equation (1), as shown below:

$$Y_{it} = f(x_{it}\,;\,\beta).\exp(V_{it} - U_{it}) \text{ with } i,t = 1,\ldots, n \qquad (1)$$

where Y_{it} represents the production of the i^{th} firm at time t; x_{it} are the inputs, which represent land, capital and labor for a production function applied to agriculture; β are the parameters, or coefficients, estimated for the production function; $\exp(V_{it} - U_{it})$ represents the random set containing one component of error and another one of inefficiencies; V_{it} is the stochastic error which can shift the production frontier; and U_{it} represents the technical inefficiency, the second random component, which is the purpose of applying the model to explain inefficiencies.

The term U_{it} has non-negative and unilateral distribution, and can have half-normal, exponential or truncated-normal distribution. The V_{it} distribution is bilateral and reflects the random effects (nonsystematic), measurement errors and errors of the variables omitted in the model (specification error).

The model presented in equation (1) considers both random components. To obtain the stochastic frontier production simply calculate the estimated production, removing the inefficiency component of the model. The estimate of the frontier is given by:

$$Y_{it} = f(x_{it}\,;\,\beta).\exp(V_{it}) \text{ with } i,t = 1,\ldots, n \tag{2}$$

In equation (1), U_{it} represents a measure of inefficiency, while the purpose of the model is to explain the technical efficiency (TE_{it}) as a random component, which is determined by the relation between the actual production and frontier production for each observation. Accordingly, the technical efficiency estimate is given by:

$$\mathrm{TE}_{it} = \frac{Y_{it}}{{Y_{it}}^{*}} = \frac{f(x_{it}\,;\,\beta).\exp\,(V_{it} - U_{it})}{f(x_{it}\,;\,\beta).\exp\,(V_{it})} \tag{3}$$

A2. Brief discussion of the estimation process

The process to estimate efficiency can be completed either in two stages or in one stage. Sharif and Dar (1996) and Wang, Cramer and Wailes (1996) use two-stage processes to estimate the efficiency of rice farmers in India and China, respectively. In the first stage, the parameters of frontier production function are estimated, disregarding the effects of firm characteristics on inefficiency. In the second stage, the inefficiencies are estimated by regression of the random component of the first stage, on the firm characteristics explanatory for inefficiency. Coelli (1996) asserts that the assumptions on the independence of the inefficiency effects in the two-stage procedure produce two sources of bias. The first source is related to the bias on the regression parameters, as a result of the correlation and endogeneity between productive inputs (land, capital and labor) and the firm characteristics (explanatory variables for inefficiency). The second source occurs when the effect of the firm characteristics is ignored in the first stage of the frontier estimation, thereafter producing a sub-dispersion of the inefficiency measures in the second stage. The effect of the firm characteristics on the inefficiencies is biased tending to zero (Wang and Schmidt, 2009).

In contrast, the one-step method developed by Battese and Coelli (1995) allows for the simultaneous estimation of the stochastic frontier production and inefficiency measures according to firm characteristics, thereby illustrating the relative differences among the production units. The authors extended previous stochastic frontier production models, considering that the inefficiency effects are given by a linear function of explanatory variables for inefficiency. The Battese and Coelli (1995) stochastic frontier production model can be specified as:

$$Y_{it} = x_{it}\beta + (V_{it} - U_{it}) \tag{4}$$

where Y_{it} is the production logarithm of the i^{th} firm at period t; x_{it} is a logarithmic vector ($1 \times k$) of factors of production; $\beta=(\beta_0, \beta_1,\ldots, \beta_k)$ is the vector ($k \times 1$) of unknown parameters to be estimated; V_{it} is the vector of residuals, considered independent and identically distributed (i.i.d.) and; U_{it} has distribution $U_{it} \sim N^+(m_{it},\sigma^2)$, where $m_{it} = z_{it}\delta$ and z_{it} is the vector of variables that may influence production efficiency (δ).

This method uses a likelihood function to maximize the adjustment of the residue to a predetermined distribution for the random component–the error component model–or to a set of variables that influence inefficiency–the efficiency effects model, which is the one we use.

The maximum likelihood function is explained as a function of the variance of the model parameters:

$$\sigma^2 = \sigma_u^2 + \sigma_v^2 \tag{5}$$

in which it defines the share of explanatory variance for inefficiency as:

$$\gamma = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2} \tag{6}$$

The model produces the best fit as more γ approaches 1, because most of the frontier deviations were explained by the component of technical inefficiency (U_{it}). A common criticism made regarding the analysis of stochastic frontier production is that there would not be a priori reason to assume a particular form of distribution for the effects on the random component of technical inefficiency (U_{it}). Usually problems are observed when using distributions with central tendency with mode at zero, as in the half-normal distribution. Distributions with mode at zero result in many inefficient companies to few efficient companies, because the majority of the U_{it} tends to approach zero (Coelli *et al.*, 2005). Stevenson (1980) utilized a model assuming a truncated-normal distribution, which is a generalization of the half-normal distribution. The truncated-normal distribution resolves the problem of the distributions with mode at zero, because it allows the use of a greater variety of forms of distribution, including a form with mode at nonzero values.

Even accepting the view that there are numerous advantages to the single-stage estimation method, additional consideration as to the method of parameter estimation, and the importance of the use of panel data models must also be given. From the outset, it is worth mentioning that the high cost of a field survey of a representative sample of land reform settlements in the Northeast of Brazil limits the duration of the sample. By the same token, limits such as these make it hardly feasible to implement more advanced models, as it will be discussed below.

Hallam and Machado (1996) stated that the restriction of independence between the levels of inputs and efficiency as a drawback of most technical efficiency studies. Battese (1998) recognizes that this is a requirement to obtain non-biased least-squares estimators for stochastic regressors, but it is not required for maximum-likelihood estimators in stochastic frontier models. The method of maximum likelihood estimation avoids the restriction of independence between the levels of inputs and efficiency. Using the Battese and Coelli (1995) model the variables associated with explaining the technical inefficiency effects may also be associated with inputs in the frontier function, as in Coelli and Battese (1996) and Huang and Liu (1994) for example.

Once the problems of consistency are resolved by the method of maximum likelihood, still remains that traditional panel stochastic frontier models do not distinguish between unobserved individual heterogeneity and inefficiency, thus forcing all time-invariant individual heterogeneity into the estimated inefficiency (Wang and Ho 2010). It is assumed that there is an evolution in the application of stochastic frontier methods that fundamentally indicates to the assessment, elimination, and if possible estimation of the fixed effects related to the firms, households or individuals, using a panel estimation method. According to Wang and Ho (2010) the goal is to avoid interpreting the individual effects as a source of inefficiencies. Similar concern is expressed by Liu and Myers (2009) that highlights the sensitivity of the obtained results (the sources of inefficiency) to the form of incorporation of firm characteristics.

Such advances and care with the estimation of individual effects match perfectly with the debate on the assessment of agrarian reform, specifically in Buainain, Silveira, and Magalhães (2000) and Silveira *et al.* (2008). These studies discuss the importance of considering the effect of land expropriation procedures and selection of beneficiaries, in addition to the external factors that influence the success of the settlements.

In the case of measuring the inefficiency, the individual component, represented by the variance of individual attributes, can be confused with the effects of variable component of the vector z_{it}. The panel data estimation applied to the PCT data, despite the limitations of a sample with $t = 2$, is considered an advance on the work of Magalhães *et al.* (2011), which estimates the efficiency of the settlers based on only one year, a cross-sectional model. The application of the panel method, according to Abdulai and Tietje (2007), by using a time-variant specification and controlling for correlations between unobserved heterogeneity and explanatory variables helps eliminate individual effects before estimation, eliminating heterogeneity bias and ensuring consistent efficiency estimates.

A3. Model Specification

The production of the beneficiaries of land reform programs is characterized by a composition of diverse agricultural products–an analysis of the agricultural system is made in appendix A. In the present model, however, we use a production function with one output variable representing the total value of agricultural production, in Brazilian Reais (R$). The area used by farmers, measured in hectares, represents the land factor, considering areas planted with seasonal and perennial crops and permanent areas of forestry farming, pasture, and forage planting, including small areas of the family's home yard. Labour days are considered as working days applied to production, for the time period of August 1999 to July 2000 and August 2004 to July 2005. The use of capital was represented by the costs (R$) of inputs, services, and other production costs.

The inefficiency term is constructed based on the theoretical framework, adapting the set of variables according to the available information. The variables included are: (i) time (*PCT2006*), to allow for time-based efficiency learning in relation to the inefficiency effects; (ii) scale (*UsedArea*), to control for the inverse relationship; (iii) state level fixed-effects (*MG, MA, CE, BA, PE*); (iv) soil quality to control for resource endowments[16] (*PSoilA, PSoilB, PSoilC*); (v) the household strategies in terms of allocation of the productive structure and income sources (*PConsumption, PCollectiveProduction, PCollectiveLabour, POuterIncome*); (vi) the technological components of agricultural systems (*Livestock, AnimalLabour, Machines, PurchasedSeeds, Fertilizers, Irrigation*); (vii) variables relating to the institutional setting – access to credit, technical assistance, and number of families in the settlement project (*Credit, TechAssistance, NumberOfFamilies*); (viii) human capital, as defined by years of formal education (*Schooling*); and (ix) level of assets to capture the household wealth (*lnAssets*).

The empirical model follows the original specification of Battese and Coelli (1995) by applying the natural logarithm (base *e*). The Cobb-Douglas production function for the stochastic frontier is defined as:

$$\ln(Y_{it}) = \beta_0 + \beta_1 \ln(UsedArea_{it}) + \beta_2 \ln(Labour_{it}) + \beta_3 \ln(Costs_{it}) + (V_{it} - U_{it}) \qquad (7)$$

where i refers to the i^{th} household and t to the year surveyed; Y_{it} is the total value of agricultural production in Brazilian Reais (R$); $UsedArea_{it}$ is the total area used with temporary and permanent crops, pastures and other areas of intensive farming (ha);

16 Following Bhalla and Roy (1988) it is now considered a misspecification error not to include soil quality. It is also recommended to include other environmental conditions, such as rainfall (Sherlund, Barrett and Adesina, 2002). Other variables such as population and road network density and some measure of transaction costs can also be included to control for the effects of isolation and market structure on production (Platteau, 2000; Stifel and Minten, 2008). Unfortunately we do not yet have this information incorporated into the data set.

$Labour_{it}$ is the number of working days during the whole year of production; $Costs_{it}$ refers to expenses for variable inputs, in Brazilian Reais (R$); β_0 to β_3 are the parameters to be estimated; V_{it} is the component for the residual (random effects, misspecification and measurement errors); and U_{it} controls for technical inefficiency. The term for technical inefficiency (U_{it}) is given by:

$$
\begin{aligned}
U_{it} = {} & \delta_0 + \delta_1(PCT2006_{it}) + \delta_2(MG_{it}) + \delta_3(MA_{it}) + \delta_4(CE_{it}) + \delta_5(BA_{it}) \\
& + \delta_6(UsedArea_{it}) + \delta_7(PSoilA_{it}) + \delta_8(PSoilB_{it}) \\
& + \delta_9(PConsumption_{it}) + \delta_{10}(PCollectiveProduction_{it}) \\
& + \delta_{11}(PCollectiveLabor_{it}) + \delta_{12}(POuterIncome_{it}) \\
& + \delta_{13}(Livestock_{it}) + \delta_{14}(AnimalLabor_{it}) \\
& + \delta_{15}(Machines_{it}) + \delta_{16}(PurchasedSeeds_{it}) \\
& + \delta_{17}(Fertilizers_{it}) + \delta_{18}(Irrigation_{it}) \\
& + \delta_{19}(TechAssistance_{it}) + \delta_{20}(Credit_{it}) \\
& + \delta_{21}(Schooling_{it}) + \delta_{22}(NumberOfFamilies_{it}) \\
& + \delta_{22}(lnAssets) \qquad (8)
\end{aligned}
$$

where *i* refers to the i^{th} household and *t* to the year surveyed; $PCT2006_{it}$ refers to the a variable capturing time; MG_{it} receives a value of 1 for the state of Minas Gerais and 0 for others; MA_{it} receives the value 1 for the state of Maranhão and 0 for others; CE_{it} takes the value 1 for the state of Ceará and 0 for others; BA_{it} receives the value 1 for the state of Bahia and 0 for others; $UsedArea_{it}$ refers to cropland, pastures, and other areas of farming (ha); $PSoilA_{it}$ refers to the proportion of municipal land with high quality soil; $PSoilB_{it}$ refers to the proportion of municipal land with medium quality soil; $PConsumption_{it}$ is the ratio of the value of production used for family consumption and the total value of production; $PCollectiveProduction_{it}$ is the ratio of the value of collective production and the total value of production; $PCollectiveLabor_{it}$ is the ratio of working days used for collective activities and the total days worked by the family during the whole production year; $POuterIncome_{it}$ is the ratio between the amount of income earned in activities outside the lot and settlement, and the total amount of income earned; $Livestock_{it}$ is assigned the value 1 for the presence of livestock and zero for absence; *Machines*$_{it}$ takes the value 1 for the use of mechanical force in production; *PurchasedSeeds*$_{it}$ receives the value 1 for the use of purchased seeds; *Fertilizers*$_{it}$ takes the value 1 for the use of fertilizers, in particular chemical fertilizers; *Irrigation*$_{it}$ assigned the value 1 for irrigated; *TechAssistance*$_{it}$ registers the value 1 if the beneficiary has received technical assistance; *Credit*$_{it}$ registers the value 1 for those receiving credit, excluding the regular funding of land reform programs; *Schooling*$_{it}$ represents the years of formal schooling of the household head; *NumberOfFamilies*$_{it}$ refers as a proxy for the size of the project. *PE*$_{it}$ (State of Pernambuco) and *PSoilC*$_{it}$ (low quality soil) are omitted to avoid perfect multicollinearity.

Finally, *lnAssets*$_{it}$ is the natural logarithm of the present value, in R$ of July 2006, of beneficiaries' individual and shared collective assets. Considered assets are: rural and urban estates, household goods, agricultural machinery, equipment and facilities, livestock, checking and savings accounts, and loans. Household goods include automobile, bicycle, motorcycle, stove, refrigerator, freezer, sewing machine, blender, electric iron, vacuum cleaner, washing machine, shower, fan, TV, VCR, DVD player, parabolic antenna, stereo, radio, sofa, and wardrobe. Agricultural machinery, equipment and facilities list include: farm machinery, plow, harrow of animal traction, planter, cultivator, sprayer pumps, cart, wagon, chainsaw, farm hand tools, water pump, irrigation kit, water tank, fence, electric fence, farm pen, corral, and barn.

B. Data

In this section we present the sampling procedure, the geographic display of the sample and a brief analysis of the summary statistics.

B1. Sampling Procedure

The data set consists of 204 households, with observations for two periods in time, 2000 and 2006. The purpose of the sample was to allow comparison between the situation of the PCT beneficiaries in 2000 and 2006, seeking a sample with the same households in both periods. Therefore the sample of households in 2006 was conditional on the sample of households in 2000. The sample was designed to cover the whole Program, which was implemented as a pilot in five states (Bahia–BA, Ceará–CE, Maranhão–MA, Minas Gerais–MG, and Pernambuco–PE). The sampling procedure was carried out in two stages, ensuring the geographic distribution of projects.

In the first stage, the projects were randomized and selected by mesoregion (geographic region within states defined by the Brazilian Institute of Geography and Statistics–IBGE). In the second stage, households were ordered according to the project size, then randomized and selected within settlement projects. The number of households selected within mesoregions was proportional to the number of households of beneficiaries existent in the region, holding a minimum of two projects in each mesoregion when possible. This process ensures randomization and guarantees observations in most mesoregions and size variability of settlement projects. Figure 1 presents the sample map.

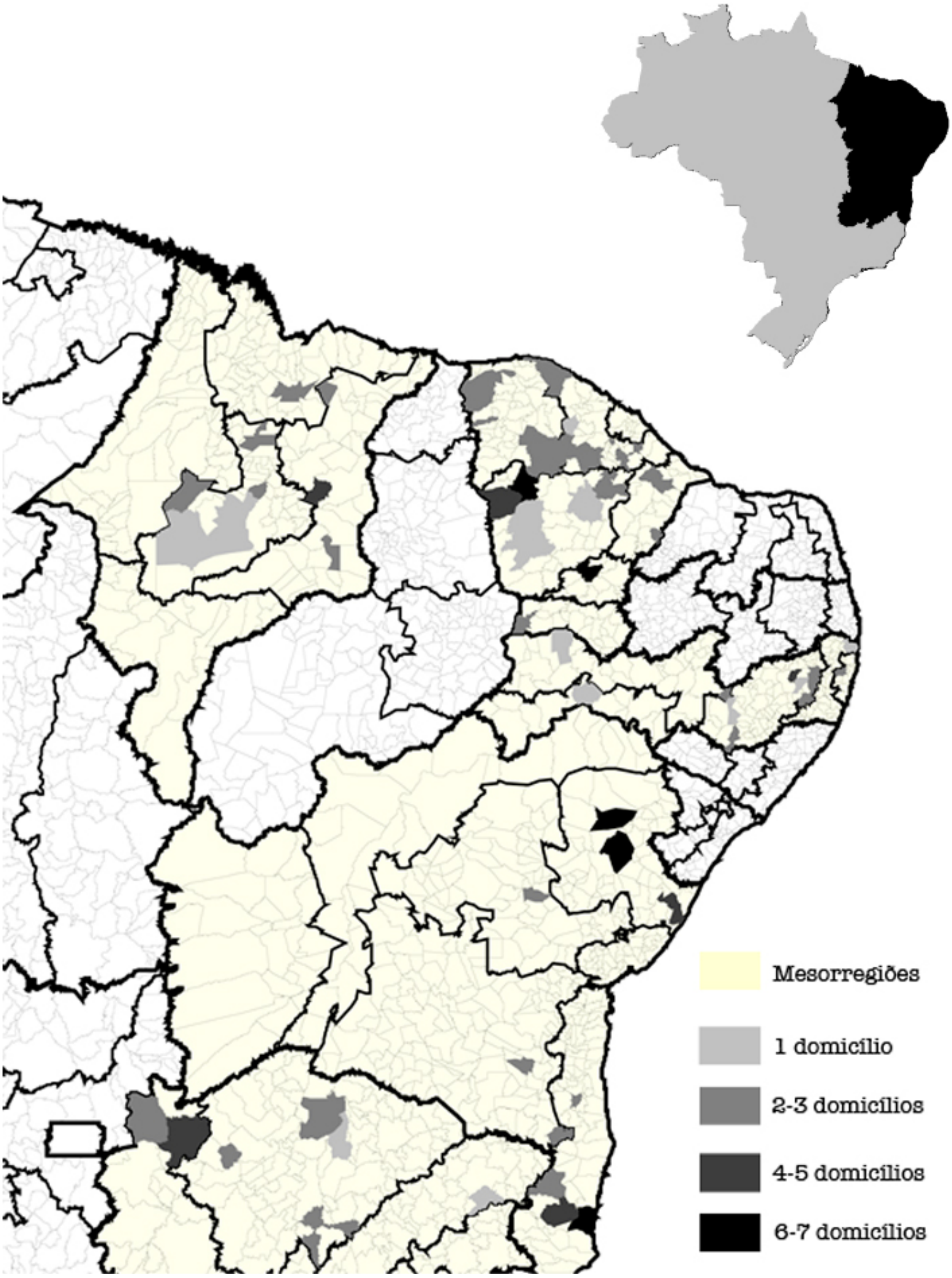


Figure 1. Geographic display of the household sample (n=204)

B2. Summary statistics

Referring to Table 1, the production value almost doubles from 2000 to 2006, from

R$2901.45 to R$5491.41, also with an increase in used area and input costs, revealing a commitment with agricultural production by the beneficiaries. In relation to production organization, self-consumption of production decreases from 54 to 47 per cent, while the proportion of outer income grows from 36 to 39 per cent from 2000 to 2006, respectively. In contrast, all collective activities cease to exist – collective production has a sharp decrease from fifteen to four per cent and collective labor days from nineteen to two per cent.

The utilization of livestock has a sharp increase from 62 per cent of the households to 90 per cent. While in 2000 almost no plots utilize animal labor (six per cent), in 2006, fifteen per cent are using animals in farming. The utilization of machines and fertilizers also increases from 32 to 43 per cent, 45 to 54 per cent, while irrigation and purchase seed remain stable at around ten and 40 per cent, respectively. Technical assistance appears constant around 45 per cent and access to credit decreases sharply, from 48 to 20 per cent. In contrast, the mean value of assets increases from R$14864.62 to R$21407.39.

The descriptive analysis has pointed to a pattern of productive organization in accordance to the serious restrictions imposed by the environment and market failures that characterize agriculture production in the semi-arid. What is disappointing is the fact that social organization changed from a more collective activity in the first years of the settlements to a production based on household individual strategies. In the next section the econometric results and index analysis will uncover the households' structure of production and clarify what happened to the beneficiaries since project installation up to a reasonably good timeframe.

Table 1. Summary statistics for the sample of PCT households, 2000 and 2006 (n=204).

Variable	2000 (n=204)			2006 (n=204)		
	Mean	Standard Deviation	Median	Mean	Standard Deviation	Median
Production value (R$)***	2901.45	4087.94	1792.40	5491.41	7265.35	3294.18
Used area (ha)***	6.22	6.37	4.04	9.52	9.66	6.30
Labor days***	579.52	419.33	484.50	389.15	673.26	206.38
Costs (R$)***	689.50	1179.03	274.10	1495.79	2382.70	747.00
BA (proportion)	0.22	0.41	-	0.22	0.41	-
CE (proportion)	0.35	0.48	-	0.35	0.48	-
MA (proportion)	0.16	0.37	-	0.16	0.37	-
MG (proportion)	0.12	0.33	-	0.12	0.33	-
PE (proportion)	0.15	0.36	-	0.15	0.36	-
High quality soil (ratio of county area)	0.49	0.40	0.45	0.49	0.40	0.45
Regular quality soil (ratio of county area)	0.24	0.33	0.05	0.24	0.33	0.05
Low quality soil (ratio of county area)	0.27	0.32	0.08	0.27	0.32	0.08
Self-consumption (ratio of production)**	0.54	0.33	0.54	0.47	0.32	0.43
Collective production (ratio of production)***	0.15	0.26	0.00	0.04	0.12	0.00
Collective labour (ratio of labour days)***	0.19	0.25	0.10	0.02	0.14	0.00
Outer income (ratio of income)*	0.36	0.32	0.35	0.39	0.30	0.33
Livestock (proportion)***	0.62	0.49	-	0.90	0.30	-
Animal labour (proportion)***	0.06	0.24	-	0.15	0.36	-
Machines (proportion)**	0.32	0.47	-	0.43	0.50	-
Purchased seeds (proportion)	0.44	0.50	-	0.36	0.48	-
Fertilizers (proportion)*	0.45	0.50	-	0.54	0.50	-
Irrigation (proportion)	0.07	0.25	-	0.10	0.30	-
Technical assistance (proportion)	0.49	0.50	-	0.43	0.50	-
Credit (proportion)***	0.48	0.50	-	0.20	0.40	-
Schooling of the head (years)	1.86	2.17	-	2.21	2.65	-
Number of families into the project	32.88	21.39	30.00	33.02	21.61	30.00
Assets (R$)***	14864.62	9959.42	12360.07	21407.39	13765.30	18537.43

Note: * 10%; ** 5% ; *** 1% of significance.[17]
Source: Original data from Silveira *et al*. (2008).

[17] We apply here and throughout the paper the Mann-Whitney-Wilcoxon test for continuous variables and the $\chi 2$ test for discrete variables to compare the variables' means between groups, in the case of Table 1 between years.

IV. Empirical Analysis

In this section we analyze the results of the econometric estimation of the panel data model. First, the analysis of the factors of production and the sources of efficiency is completed, followed by the analysis of technical efficiency index for the years 2000 and 2006. Finally, the analysis is concluded by characterizing the households near the frontier for both years, by selecting the band of the 20% highest values of the technical efficiency index, against the 50%, 30%, 20%, and 10% lower values.

A. Econometric estimation

Obtained estimates, presented in Table 2, for the variance of the model parameters (σ^2 = 0.88) and the portion of variance attributed to the inefficiency explanatory parameters (γ = 0.52) are statistically significant. The likelihood ratio test indicates that the model expresses inefficiency with the highest level of statistical significance. The value obtained in the test was 184.9 considering the χ^2 distribution with 30 degrees of freedom.

The production presented diminishing returns for factors of production, with statistical significance for the partial elasticities of used area and costs. Used area presented the higher partial elasticity (β_1 = 0.23) followed by costs (β_3 = 0.11), much greater than labour (β_2 = 0.03), which has a statistically insignificant parameter. Between 2000 and 2006 there was an overall substitution of labour by capital and land, which caused the decrease of partial productivity of capital and the increase for land. The amount of used area (δ_6 = 0.02) does indeed have a positive effect on inefficiency, in alignment with the inverse relationship stylized fact, however the effect is very small and statistically insignificant, which could be due to the small variance of plot size, not allowing to significantly corroborate the existence of an inverse relationship. In addition, the time variable (δ_1 = -0.5) points to a positive effect on the production value, indicating learning really did take place.

The presence of a higher proportion of high (δ_7 = -0.57) and regular (δ_8 = -0.61) soil quality in the municipalities, which is indicative of better resource endowments, also contributes to increase technical efficiency.

In terms of livelihood strategies, there is evidence that the allocation of labour to collective activities in the project resulted in a strong positive effect on efficiency (δ_{11} = -1.26). While the allocation of obtained products to self-consumption (δ_9 = 0.86) and the reliance on external sources of income (δ_{12} = 1.42) were the largest negative influences on technical efficiency. Although allocation of production for self-consumption and the existence of an exogenous source of income are important for food security and consumption smoothing, they are often a sign of asset smoothing and the choice of a low-risk low-return strategy caused by either, or a combination of, factor and product market failure, low level of wealth, and social norms. The high and positive statistical significance of the level of assets (δ_{24} = -0.46) on technical efficiency corroborates this explanation.

In relation to the agricultural system and technological intensity, the existence of livestock (δ_{13} = -0.34) positively affects efficiency. This result can be explained by the short-term gains in animal production, that is, milk and dairy products, and the possibility of increasing technological intensity with animal traction. Accordingly, the existence of animal labour (δ_{14} = -0.44) also contributes to increase efficiency. On the other hand, the goal of drought risk reduction is contrary to short-term gains, as animals are selected for their resistance to drought and as a savings mechanism, instead of being chosen for other characteristics that favor efficiency gains in the short-term, which would explain the small effect of the *Livestock* parameter.

Furthermore, the presence of irrigation ($\delta_{18} = -0.61$) also contributes to raise efficiency, while the presence of agricultural machines, purchased seeds, and fertilizers are statistically insignificant. Access to credit, technical assistance, schooling, and number of families in the projects all have statistically insignificant parameters as well.

Table 2. Results of the stochastic frontier with efficiency effects panel data model, 2000 and 2006 (n=204).

Parameters			Estimates	Standard Error	Pr(>|z|)
Factors of Production	β_0	*Intercept****	8.05	0.49	< 2.2e-16
	β_1	*lnUsedArea***	0.23	0.10	0.01
	β_2	*lnLabour*	0.03	0.04	0.42
	β_3	*lnCosts****	0.11	0.03	0.00
Sources of Inefficiency	δ_0	*Intercept****	6.38	1.26	0.00
	δ_1	*PCT2006****	-0.50	0.18	0.01
	δ_2	*MG**	-0.51	0.30	0.08
	δ_3	*MA*****	-1.05	0.29	0.00
	δ_4	*CE***	-0.62	0.28	0.03
	δ_5	*BA*	-0.07	0.25	0.78
	δ_6	*UsedArea*	0.02	0.01	0.26
	δ_7	*PSoilA***	-0.57	0.26	0.03
	δ_8	*PSoilB***	-0.61	0.26	0.02
	δ_9	*Pconsumption****	0.86	0.26	0.00
	δ_{10}	*PCollectiveProduction*	0.05	0.35	0.88
	δ_{11}	*PCollectiveLabour****	-1.26	0.45	0.01
	δ_{12}	*POuterIncome****	1.42	0.21	0.00
	δ_{13}	*Livestock**	-0.34	0.19	0.07
	δ_{14}	*AnimalLabour**	-0.44	0.26	0.09
	δ_{15}	*Machines*	0.03	0.16	0.85
	δ_{16}	*PurchasedSeeds*	0.21	0.17	0.22
	δ_{17}	*Fertilizers*	0.04	0.13	0.74
	δ_{18}	*Irrigation**	-0.61	0.33	0.06
	δ_{19}	*TechAssistance*	-0.17	0.16	0.29
	δ_{20}	*Credit*	0.00	0.15	0.99
	δ_{21}	*Schooling*	0.02	0.03	0.46
	δ_{22}	*NumberOfFamilies*	0.00	0.00	0.80
	δ_{24}	*lnAssets****	-0.46	0.13	0.00
	σ^2	*sigmaSquared****	0.88	0.11	0.00
	γ	*gamma****	0.52	0.16	0.00

Note: * 10%; ** 5% ; *** 1% of significance.

B. The technical efficiency index

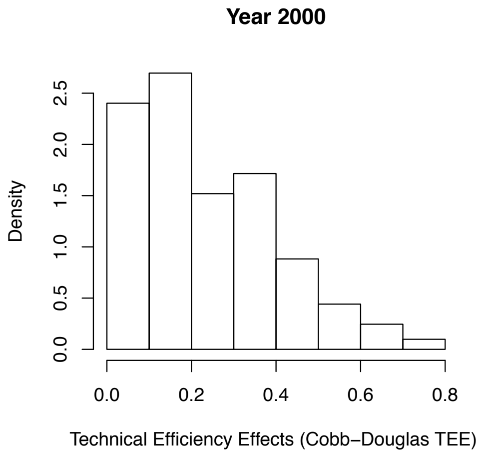
The estimate for the technical efficiency (TE) index, presented on Table 3, indicates that productive efficiency of the beneficiaries increased in the period between 2000 and 2006. The index increased from 0.24 to 0.36 in 2006, with the highest statistical significance for the variation in the period (p-value(t)=0.0001).

Table 3. Estimated efficiency for the sample of PCT households, 2000 and 2006 (n=204)

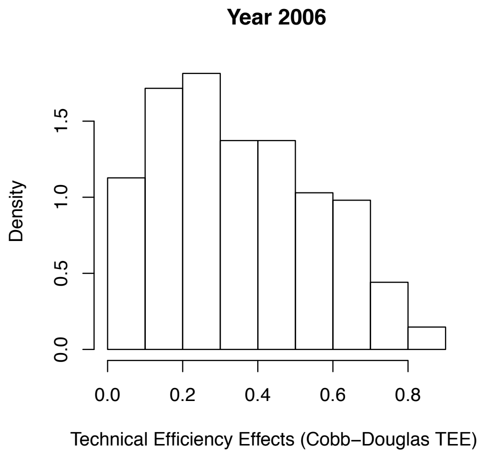
Variable	2000 (n=204)			2006 (n=204)		
	Mean	Standard Deviation	Median	Mean	Standard Deviation	Median
Efficiency***	0.24	0.16	0.19	0.36	0.21	0.32

Note: *** 1% of significance.

The histogram of the TE index, in Figure 2, brings forth a graphic representation of the concentration of observations around lower values of efficiency for 2000, when compared to the distribution of the values obtained for 2006. Whereas in Figure 3 a scatterplot is presented to reveal, within the TE index, the degree of mobility between the years.



(a)



(b)

Figure 2. Distribution of households according to the TE index, 2000-2006: (a) 2000 (n=204), (b) 2006 (n=204)

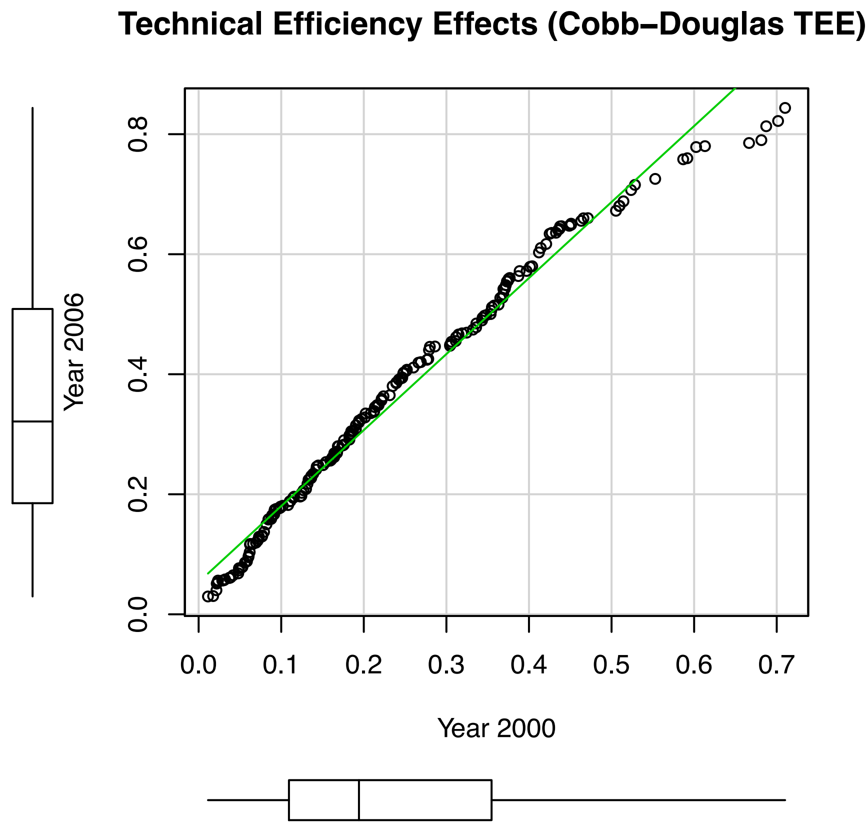


Figure 3. Scatterplot of the TE index, 2000 vs 2006 (n=204)

C. Frontier analysis of the TE index

The frontier region was established as the band of 20% households who obtained the top scores on the TE index. This band corresponds to 41 observations with the index mean of 0.49 in 2000 and 0.67 in 2006. The analysis developed presents statistical tests of the top 20 per cent against the lower 50 (n=102), 30 (n=61), 20 (n=41), and ten per cent (n=21). Therefore, the comparative analysis is always of the lower bands against the top households. The analysis is of a descriptive manner, hence it cannot yield causality conclusions as to what causes households to be in one band or another, but reveals the overall pattern of characteristics present in both efficient and inefficient households.

The results for the years 2000 and 2006, presented respectively in Table 4 and Table 5, indicate that the majority of the households have very low levels of technical efficiency. In relation to the production value and costs, there is a sharp difference between the lower bands and the top band, which indicates that the most efficient households have a much more intensive use of factors of production.

It stands out, in the year 2000, the much lower proportion of low quality soils in the upper 20 per cent band. Resource endowments, therefore, is determinant for initial success in achieving higher technical efficiency.

The variables that did not stand out in the econometric estimation but now seem of determinant importance in the initial period as well are technical assistance and access to credit. The most efficient households in the year 2000 had overwhelming more access to both features. Furthermore, for both years, 2000 and 2006, smaller projects (fewer families involved) are closer to the frontier, revealing governance problems in projects with more than 30 families.

The rest of the statically significant variables deepen the understanding found with the econometric estimation of the parameters. Self-consumption and outer income are significantly higher in the lower bands of efficiency in comparison to the top band, whereas collective labour presents the inverse movement. Also following the econometric estimation, the presence of livestock and animal labour and the value of the assets are much higher within the top 20 per cent households.

Table 4. Mean value of model's variables according to selected TE index bandwidths, 2000

Variable	Mean Values				
	10% Lower (n=21)	20% Lower (n=41)	30% Lower (n=61)	50% Lower (n=102)	20% Upper (n=41)
Technical Efficiency Index	0.04*	0.06*	0.07*	0.11*	0.49
Production value (R$)	222.05*	349.81*	594.00*	946.52*	7191.39
Used area (ha)	5.41	5.15	6.08	6.14	6.39
Labour days	685.57	576.90	618.84	596.21	578.34
Costs (R$)	307.72*	317.62*	366.74*	507.86*	1258.41
High quality soil (ratio of county area)	0.30*	0.41*	0.37*	0.42*	0.57
Regular quality soil (ratio of county area)	0.21	0.19	0.26	0.22	0.28
Low quality soil (ratio of county area)	0.49*	0.40*	0.37*	0.36*	0.15
Self-consumption (ratio of production)	0.76*	0.72*	0.67*	0.59*	0.44
Collective production (ratio of production)	0.03*	0.07	0.08	0.14	0.16
Collective labour (ratio of labour days)	0.08*	0.08*	0.10*	0.15*	0.27
Outer income (ratio of income)	0.63*	0.52*	0.55*	0.50*	0.16
Livestock (proportion)	0.52*	0.51*	0.52*	0.55*	0.78
Animal labour (proportion)	0.05	0.02*	0.05*	0.04*	0.15
Machines (proportion)	0.33	0.34	0.36	0.31	0.37
Purchased seeds (proportion)	0.62*	0.61*	0.59*	0.50*	0.34
Fertilizers (proportion)	0.43	0.37*	0.34*	0.39*	0.56
Irrigation (proportion)	0.10	0.05	0.05	0.05	0.12
Technical assistance (proportion)	0.10*	0.24*	0.31*	0.35*	0.71
Credit (proportion)	0.29*	0.24*	0.31*	0.36*	0.66
Schooling of the head (years)	2.29	1.85	1.90	1.97	1.56
Number of families in the project	34.48	38.29*	36.79*	36.43*	29.10
Assets (R$)	10072.26*	12175.34*	12575.22	13682.50	16828.82

Note: * at least 10% of significance.

Table 5. Mean value of model's variables according to selected TE index bandwidths, 2006

Variable	Mean Values				
	10% Lower (n=21)	20% Lower (n=41)	30% Lower (n=61)	50% Lower (n=102)	20% Upper (n=41)
Technical Efficiency Index	0.06*	0.10*	0.13*	0.18*	0.67
Production value (R$)	504.01*	865.21*	1193.10*	1774.27*	14556.46
Used area (ha)	11.53	12.05	12.81	10.45	8.33
Labour days	466.71	343.68	319.99	368.16	468.02
Costs (R$)	843.60	787.10*	969.89*	1279.58*	1670.57
High quality soil (ratio of county area)	0.48	0.51	0.49	0.50	0.44
Regular quality soil (ratio of county area)	0.23*	0.22*	0.22*	0.22*	0.35
Low quality soil (ratio of county area)	0.29	0.27	0.29	0.29	0.21
Self-consumption (ratio of production)	0.68*	0.57*	0.57*	0.52*	0.39
Collective production (ratio of production)	0.01*	0.04	0.04	0.04	0.04
Collective labour (ratio of labour days)	0.00	0.02	0.02*	0.01*	0.05
Outer income (ratio of income)	0.82*	0.75*	0.66*	0.55*	0.23
Livestock (proportion)	0.76*	0.78*	0.84*	0.84*	0.98
Animal labour (proportion)	0.05*	0.05*	0.05*	0.09*	0.32
Machines (proportion)	0.24*	0.34	0.36	0.45	0.46
Purchased seeds (proportion)	0.43	0.41*	0.38	0.39*	0.24
Fertilizers (proportion)	0.43	0.49	0.49	0.55	0.61
Irrigation (proportion)	0.00*	0.02*	0.05*	0.08	0.15
Technical assistance (proportion)	0.38	0.39	0.43	0.41	0.49
Credit (proportion)	0.10	0.22	0.21	0.25	0.22
Schooling of the head (years)	2.62	2.46	2.34	2.12	2.32
Number of families in the project	35.57*	33.66*	30.98	31.96*	27.07
Assets (R$)	16614.54*	15330.26*	15400.88*	18057.41*	32004.77

Note: * at least 10% of significance.

V. Discussion and policy implications

The overall pattern reveled in this study is that beneficiaries' success depends on a fine-tuning of a set of variables in a very rigid and cumbersome environment. With great accordance to the results presented by Magalhães *et al.* (2012), which compared state-led land reform and PCT settlements, efficiency analysis has shown that either the clear expectation of assignment of complete property rights and/or the existence of a bundle of incentive (sequential) mechanisms were not enough to generate a governance structure based on the selection of only high quality land, collective use of resources and the strengthening of cooperative forms of production organization.

The different structures of production were clearly mapped, on the inefficient side appears a clear choice or imposition of the low-risk low-return strategy, with low intensity on the use of the factors of production, initially high proportion of low quality land, participation in projects with a larger number families, allocation of more then half of production for self-consumption and strong reliance on outer sources of income (which most of the time are of low quality–in urban civil construction, informal rural labour contracts bellow minimum wage established on a daily basis, or inefficient/unfair sharecropping arrangements in surrounding large properties).

Therefore, the assignment of property rights *per se* is not a panacea and land redistribution should be thought in conjunction with other institutions that are of great importance such as access to credit, technical assistance, and product markets, which absence in the initial phase of installation can doom households to failure. In addition, smaller size associations should be prioritised, facilitating governance with cooperation and evolution of social norms. Land redistribution should also be thought relating to the presence of livestock and level of assets that a household enters the program, because these variables influence the ability to choose the level of technology applied to the production, influencing the use of animal labour and irrigation.

The level of assets, in accordance with the asset-based poverty trap literature (Zimmerman and Carter, 2003; Carter and Barrett, 2006; Carter and Lybbert, 2012), is therefore important for achieving higher technical efficiency in the panel period. Observing Figure 3 and the comparative analysis with xxx it appears that an ‘inefficiency trap’ may exist as well, which is not solely determined by the level of assets, but also related to institutional, technological, and organisational factors. To which degree each variable determines the threshold of the trap, and if the trap itself exists, is certainly a subject for further inquiry.

VI. Concluding remarks

In this paper we apply a stochastic frontier production function model to panel data of 204 households beneficiaries of market-assisted land reform in the Brazilian Northeast region. The gain in production between 2000 and 2006 is irrefutable, although small gains in technical efficiency are observed. The technical efficiency index increased from 0.24 to 0.36 during the period between 2000 and 2006.

In addition to adverse agroclimatic conditions, product and factor markets in Northeastern Brazil are very thin when not missing. The structure of governance devised to overcome these conditions and establish social capital towards a more efficient production depend on many issues, such as the initial singular conditions under which beneficiary enters the program, a good process of assortative matching of relatively homogenous beneficiaries without political interference, and the completeness of property rights based on group cooperation with effective management of common resources.

This leads to the success of only a part of the households participating in the program. Success is thus dependent on initial access to technical assistance, credit, and good resource endowments, group cooperation with collective labor, overcoming the low-risk low-return strategy, which is exemplified by the high rate of outer income and self-consumption of the inefficient beneficiaries. Technically efficient households would have work towards a more market-oriented production with intensified use of factors of production and increased levels of livestock, animal labor, and irrigation in a project with less then 30 families. In conclusion, the results obtained suggest that technical efficiency in land reform settlements remains an open issue, particularly for projects installed by market-assisted policies.

Appendix A. Agricultural Systems

This section analyses summary statistics, presented on table A1, for both years of the panel to identify the general production system setup by the settled households. Overall the used areas of pasture, perennial crops, and annual crops increased, enhancing food security.

The enhancement of food security is exemplified by the continuity of a great presence of corn, at a mean around 65%, and the increase in the mean presence of items such as milk–from 25% of the households in 2000 to 45% in 2006–, egg from 25% to 68%, cassava from 20% to 34%, and rice and beans, which remain steady. The presence of processed products, perennial crops, and annual crops rose from 25% to 35%, 15% to 47% and 81% to 89%, respectively. Furthermore, the presence of livestock also increases: pig, equids, and poultry rose from 28% to 48%, 28% to 61%, and 58% to 78%, respectively. Goat and sheep remain unchanged.

The systems of production, over and above, show a tendency to shift towards higher use of land area for pasture activities, which expanded from a mean of 1.42 to 4.65 hectares and from a ratio in relation to the total area of 14% to 31%. However, the expansion of pasture should not view as a movement of substitution in relation to crop lands, as the area of perennial crops increased from 1.09 to 1.82 hectares, while the area of annual crops remained steady around 2.7 hectares. The implications of these changes on technical efficiency and profitability of investments could be a subject for further investigation.

Table A 1. Summary statistics of the agricultural system for the sample of PCT households, 2000 and 2006 (n=204)

Variable	2000 (n=204)			2006 (n=204)		
	Mean	Standard Deviation	Median	Mean	Standard Deviation	Median
Area of pasture (ha)*	1.42	3.14	0.00	4.65	8.13	1.00
Area of pasture (ratio)*	0.14	0.25	0.00	0.31	0.34	0.18
Area of perennial crops (ha)*	1.09	2.77	0.00	1.82	3.71	0.01
Area of perennial crops (ratio)	0.19	0.28	0.00	0.22	0.30	0.00
Area of annual crops (ha)	2.69	2.15	2.03	3.05	3.62	2.00
Area of annual crops (ratio)*	0.59	0.34	0.59	0.47	0.35	0.43
Dummies (proportion)						
Pig*	0.28	0.45	-	0.48	0.50	-
Goat	0.11	0.32	-	0.14	0.35	-
Sheep*	0.15	0.36	-	0.19	0.39	-
Equids*	0.28	0.45	-	0.61	0.49	-
Poultry*	0.58	0.50	-	0.78	0.41	-
Milk*	0.25	0.44	-	0.45	0.50	-
Egg*	0.25	0.43	-	0.68	0.47	-
Pasture*	0.34	0.48	-	0.58	0.49	-
Forage*	0.24	0.43	-	0.05	0.23	-
Hort*	0.28	0.45	-	0.19	0.39	-
Forestry	0.28	0.45	-	0.29	0.45	-
Perennial crops*	0.15	0.36	-	0.47	0.50	-
Annual crops*	0.81	0.39	-	0.89	0.31	-
Processed products*	0.25	0.43	-	0.35	0.48	-
Beans	0.65	0.48	-	0.72	0.45	-
Corn	0.67	0.47	-	0.65	0.48	-
Cassava*	0.20	0.40	-	0.34	0.47	-
Rice	0.15	0.36	-	0.21	0.41	-
Wooden	0.20	0.40	-	0.16	0.36	-
Charcoal	0.06	0.24	-	0.10	0.30	-

Note: * at least 10% of significance.

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