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Reform and efficiency of state-owned forest enterprises in Northeast China as "social firms"

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ABSTRACT

State-owned forest enterprises (SOFEs) in northeast China have experienced past economic loss and environmental degradation, causing government to seek reforms. Measurement of technical efficiency allows us to evaluate overall trends and how reforms affect production of social and environmental goods. Previous assessments have used small samples, short time periods, and viewed SOFEs as if they were profit-maximizers. We compared a traditional profit-maximization framework to an alternative "social firms" framework for SOFEs to classify inputs and outputs, and data envelopment analysis to measure the efficiency of 86 SOFEs from 2003 to 2009. We argue that the social firm framework is more appropriate for SOFEs given their stated objectives. We found no overall trend in pure technical efficiency over time for the social firm framework; however, there was an increase in pure technical efficiency for the profit maximization framework, consistent with past literature. At the same time, there were decreases in scale efficiency primarily due to higher levels of government investment. We compared groups of SOFEs that underwent a specific pilot forest tenure reform to those that did not, and we found no evidence to support that tenure reform improved technical efficiency.

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Introduction

Northeast state-owned forestland is an important part of the forest sector in China. State-owned forestland comprises a significant portion of China's forestland area and timber stock (Fig. 1). State-owned forest enterprises (SOFEs) are local administrative agencies which plan and implement harvesting and reforestation on state-owned forestland. 87 of 135 Chinese SOFEs are in northeast China, and they play important roles in timber production and ecological construction[1] and protection (Jiang et al., 2014). SOFEs in northeast China have more forestland area than SOFEs in the other regions combined (SFA, 2007–2014). Northeast SOFEs have been core industrial timber producers since 1950, making contributions to regional economic and social development.

SOFEs follow executive guidelines set by the central government, and rely on government for funding (Xu et al., 2004b). At the same time, the central government sets maximum annual logging quotas. However, SOFEs have encountered some issues with unsus-

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[1] "Ecological construction" is a term used in China to describe the policy of ecological restoration and other efforts to improve the ecological function and resilience of agroecosystems, including activities such as "fencing grassland, planting trees, shrubs, and grass, and irrigating cropland" (Jiang, 2006).

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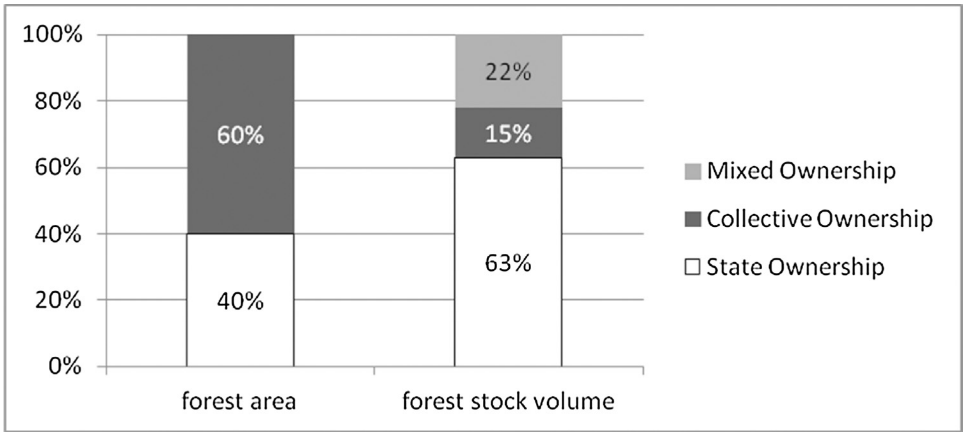

Fig. 1. Comparison of forest area and stock volume of state-owned and collective forestry.

Source: ENFRI (2014)

tainable business and development models, leading them into a situation of "two crises" – ecological degradation and economic loss (Zhang, 1998). In order to address the institutional issues and relative inefficiencies in this system, numerous policy adjustments and reforms have been undertaken, including a pilot forest tenure reform in a few SOFEs beginning in 2006.

Past studies have estimated the efficiency of Chinese SOFEs, either to identify areas of inefficiency for improved management (Liu and Yu, 2006), or to evaluate the impact of reforms (Chen and Jiang, 2013; Fu and Geng, 2012; Zhu and Jing, 2011). These studies have tended to reveal increasing average efficiency of SOFEs, and attribute this to reforms, justifying further expansion of the reforms. We find three shortcomings of these approaches. First, some of the past studies have used only a relatively small sample of SOFEs. Second, these studies use data of only two or three years, which may be subject to short-term macroeconomic changes and other variability. Due to the long growth cycle of forests, some longer-term improvements may be difficult to detect in the short-term. On the other hand, measures of some intermediate outcomes such as number of hectares reforested can be easily measured in the short-term, and can provide evidence as to whether reforms intended to align individual with community and national incentive structures have had the desired effect (Yin et al., 2013a). Therefore, a data set of intermediate length, perhaps of 5–10 years, may be desirable to evaluate the short-term reform effects while smoothing out yearly fluctuations.

Finally, and in our view most importantly, the efficiency studies of SOFEs tend to evaluate them as if they were profit-maximizing firms – attempting to increase revenue or forest management activities per input of land, labor, and capital. However, the stated objectives of the government for SOFEs deviate significantly from profit maximization. SOFEs are likely viewed very differently by the national government, the owner of the SOFEs, as well as local communities and governments – as "social firms"[2] that have the overall goal of improving wellbeing among the local community by increasing economic, environmental, and social outcomes (Bozec et al., 2002; Peredo and Chrisman, 2003; Soviana, 2015; State Council, 2015; Antinori and Bray, 2005). This could lead to researchers misclassifying inputs and outputs and calculating efficiency scores that are not in line with the true objectives of the SOFEs.

The purpose of this research is to evaluate the efficiency of SOFEs during part of this reform period, from 2003 to 2009, comparing the traditional profit-maximization framework to classify inputs and outputs with an alternative framework of SOFEs as "social firms". Our study uses available data from 86 Northeast SOFEs (excluding Dailing Forest Experimental Bureau, which has different objectives) from four years (2003, 2005, 2007, and 2009) during this seven-year period to estimate technical efficiency: (1) to identify overall trends in the sector during a period of ongoing policy reforms, and (2) to compare the efficiency of SOFEs undergoing a specific pilot tenure reform to those not undergoing the pilot tenure reform. Finally, we discuss future opportunities, challenges, and needs.

Background

Historical Perspective of Chinese SOFEs

Most of the SOFEs in northeast China (Heilongjiang Province, Jilin Province, and Inner Mongolia Autonomous Region) were established in the early 1950s. In the 1950s and 1960s, the SOFEs' main task was to provide a large amount of raw material for the development of heavy industry. Thus, SOFEs became forest logging enterprises focused primarily on timber harvest. In this period, the total number of forest workers and family members in northeast grew rapidly with the vigorous development of local forest economy. The population of people dependent on SOFEs – including workers, retirees, and family members grew steadily until about 2004, and has since declined.

On average, forest workers have relatively low educational background and technical skills (Wan, 2004), and in many rural areas, SOFEs are one of the few employment opportunities available to them. Furthermore, forest workers tend to depend on SOFEs, including basic living guarantee, annuities after retirement, housing and medical treatment due to China's planned economic system, relatively closed area and lack of labor.

Over-exploitation and deforestation without attention to management and regeneration caused a decrease in mature forests, severe disruption of stand composition, and loss of forest quality and functions (Yu et al., 2011). Therefore, by the late 1970s, northeast SOFEs had entered a period of ecological degradation and economic loss, which Zhang (1998) called the "two crises".

Beginning in 1980, China's State Forest Administration (SFA) launched a number of forest preservation projects and policy adjustments to alleviate the increased resource pressure; however,

[2] Since some readers may have different interpretations of this term, it is important to note that we use the term "social firm" in the sense described by Antinori and Bray (2005). The term contrasts to profit-maximizing firms, as social firms optimize various benefits to the community and/or nation, rather than simply generating maximum revenue at minimum cost. We develop this concept in more detail in the Background and Methods sections.

the forestry "two crises" situation was not fundamentally resolved (Chen et al., 2004). While on the surface, all SOFEs must comply with logging quotas (Alford and Shen, 1997; Brandt and Zhu, 2000), the government did not have a system to monitor SOFEs' decision-making (Jiang, 2006). The underlying reason may be that the central government and SOFEs had incompatible goals: the central government focused on ecological construction and protection, while SOFEs were interested primarily in timber harvests and other traditional functions (Xu et al., 2004b; Wang et al., 2013).

After extreme flooding in 1998, partially attributed to a loss of forest cover, China shifted the focus of forest management from wood production to ecological restoration and sustainability (Chen et al., 2004). China began to expand the Natural Forest Protection Program (NFPP) and attempted to carry through a new forest management system. Gradually, timber harvesting levels in northeast China has tended to decline, and forest area and stocking levels have slowly increased (Yu et al., 2011). At the same time, the government significantly increased its financial support to the SOFEs and initiated several reforms to improve the efficiency of forest resource management and protection; that is, to increase economic, ecological, and social outputs with fixed government investment (SFA, 2010).

Pilot Forest Tenure Reforms

To better align the goals of the government with those of the SOFEs, some have suggested forest tenure reform and the restructuring of the SFA (Yin et al., 2013b; Cui et al., 2010). Since 2003, a new wave of forest tenure reforms has been piloted in some regions of China (Wang et al., 2007; Yin et al., 2013a). Where this tenure reform has taken place, forestland use rights are devolved from SOFEs to households individually or to small groups (Hyde et al., 2003). The objective of this transformation is to improve the incentives for better forestland management, by closely coupling institutional change, governance, management responsibilities, and benefits. If successful, it is believed that this could lead to improved forest management and human wellbeing (Xu, 2010).

In 2006, the State Council approved and piloted forest tenure reforms in five SOFEs in northeast China, in the area of Yichun municipality, Heilongjiang province: Shuangfeng, Tieli, Taoshan, Wumahe, Cuiluan (Xu, 2010). Forest tenure reforms were piloted first in Yichun because the municipal government had been an advocate of forest enterprise reform, and expected the reform to increase wages and improve forest quality (Wan and Wu, 2009). Forest tenure reforms call for deliberate thinking about institutional systems – assignment of forest holdings, restructuring of the SFA, and creation of legal access and exclusion mechanisms (Yin et al., 2013a). Meanwhile, pilot forest tenure reform has created many smallholders in a short period, posing regulatory challenges. Most forest workers have not yet received forest certificates, so they have no collateral to access credit. Therefore there may be little enthusiasm for tree planting and forest management, and a perception of little security in their property rights (Zhang, 2012).

Data Envelopment Analyses of Forest Management Efficiency

In this context of SOFEs' "two crises" and ongoing reforms, it is valuable to assess and evaluate trends in economic efficiency to determine if progress is being made towards more productive SOFEs. Forests differ from other resources, because of the long growth cycle and multiplicity of inputs and outputs; moreover, the "success" of forest tenure reform must be defined from the short-term and the long-term perspectives (Ostrom, 2007; Yin et al., 2010). Therefore, assessing the effectiveness or trying to predict the likely outcomes of China's forest tenure reform requires careful and continuous observation and analysis.

Data envelopment analysis (DEA) (see Banker et al., 1984; Charnes et al., 1978) is an approach to measuring relative technical efficiency by comparing relative utilization of inputs and production of outputs among firms. Sowlati (2005) and Diaz-Balteiro and Romero (2008) summarized and reviewed past DEA studies of the forestry sector and found they have included evaluations of forest regional planning and forest industry. While the studies span the globe geographically, many of the studies listed include a single economic output, such as timber output (Sowlati, 2005). For studies of forest regional planning this can severely underestimate the output of forests in places where they are valued for ecological and social outputs, and potentially could result in the misclassification of jobs as a cost rather than a social benefit of forest enterprises. Of those including ecological and social outputs, Kao and Yang (1991, 1992) included soil conservation as an ecological output and recreation as a social output to compare efficiencies of forest districts in Taiwan to determine how inefficient districts could improve. Hof et al. (2004) also recognized that forest and rangeland conditions can be viewed as inputs, and human activity as outputs. Susaeta et al. (2016) viewed forest stand conditions as inputs that produce ecological outputs such as carbon sequestration and species richness.

Some past studies have used DEA to estimate an average technical efficiency score of Chinese SOFEs over time, and then assess factors influencing the efficiency. Characteristics of these studies, including the inputs and outputs selected, and the data years, are presented in Table 1. In general, the five past studies listed in Table 1 have primarily classified employment as an input, rather than output, and tend to use total production value, or something similar, as the only or one of a few outputs. This is indicative of using an implicit framework and underlying assumptions of "profit-maximization", rather than "social firms", to select the inputs and outputs of the DEA models, as we will describe later in the Methods section.

Although this paper argues for a novel classification scheme for inputs and outputs, based on a "social firms" framework, rather than a "profit-maximization" framework utilized by most past work, it is instructive to understand that past work. Zhang (2002) found increased efficiency over the time between 1985–87 and 1995–95, and attribute this increase to the various economic reform efforts during the period. Liu and Yu (2006) found that some smaller SOFEs could increase efficiency by increasing their scale, while larger SOFEs could increase efficiency by decreasing their scale. Meanwhile, as the NFPP has been launched, TFP has been falling rapidly because of repeated construction and limited logging. Wang and Zhu (2013) showed that the efficiency was on the low side generally, and tended to fluctuate during the 10-year period. They suggested SOFEs should make technical efficiency as a basic goal and take advantage of forest resources to construct industry. Zheng and Wan (2013) found a low average technical efficiency of SOFEs in Heilongjiang province in 2010 and attribute this to wasteful management; however, a low "average" efficiency in a single year may only mean that there is a high level of heterogeneity and should not usually be interpreted as wasteful of resources (Frey et al., 2012). Zhu and Jing (2011) found that the five SOFEs that underwent a pilot tenure reform had increased efficiency over three years, and suggest the scope of the pilot project should be further expanded.

In summary, measurement of technical efficiency of Chinese SOFEs has utilized limited samples, short time spans, and, most crucially, typically implicitly assumed profit-maximization as the objective of the SOFEs. Our approach utilizes a larger sample, longer time period, and we classify inputs and outputs using a framework of SOFEs as social firms, which is the principal innovation of our research. We then compare the results from the social firm

Table 1
Characteristics of past studies using data envelopment analysis (DEA) to estimate technical efficiency of Northeast China SOFEs.

	Input variables	Output variables	Years	Area[a]	Number of SOFEs
Zhang (2002)	Total expense	Area of afforestation Area of reforestation Area of forest tending	1985–87 & 1995–97	HP	40
Liu and Yu (2006)	Employment Fixed-capital investment Current capital investment	Timber output Forestry product value Multiple industry value	1991–2002	HP, JP, IM	50
Zhu and Jing (2011)	Employment Fixed-capital investment Forestry land area	Area of afforestation Area of forest tending Total production value	2005–2007	YM	16
Zheng and Wan (2013)	Area of afforestation Area of forest tending Fixed-capital investment Employment	Total production value	2010	HP	40
Wang and Zhu (2013)	Employment Fixed-capital investment	Total production value	2000–2009	HP	40
Our research – "social firms" framework	Forestry land area Central government investment	Timber output Area of afforestation and afforestation of forest land Area of forest tending Employment Average wage	2003, 2005, 2007, 2009	HP, JP, IM	86
Our research – "profit-maximizing firms" framework	Forestry land area Employment Fixed-capital investment	Total production value	2003, 2005, 2007, 2009	HP, JP, IM	86

[a] HP = Heilongjiang Province; JP = Jilin Province; IM = Inner Mongolia Autonomous Region; YM = Yichun Municipality (a subdivision of Heilongjiang Province).

framework to results of a more conventional profit-maximization framework.

"Social Firms" and the Chinese SOFE Context

In traditional economics, most firms are assumed to have the principal objective of profit maximization. A profit-maximizing firm combines inputs to generate one or more outputs that can be sold for revenue. Fig. 2 shows a schematic of a generic profit-maximizing firm that combines inputs such as land, labor, and capital to produce some revenue-generating output.

It is best theoretically to measure performance in terms of achieving objectives rather than a single measure to apply to all types of firms (Aharoni, 2000). In contrast to profit-maximizing firms, "social enterprises" or "social firms" have core objectives other than profit, which include improving the lives of specific people or the community at large (Soviana 2015). Peredo and Chrisman (2006) noted that community-based enterprises likewise have objectives, other than profit, to benefit the community:

> It is important to note that profit-making need not be, and typically will not be, the exclusive or even the primary purpose of the enterprise. While some return is necessary to make the operation sustainable, that return may be seen as strictly instrumental in achieving some other community purpose(s), and a lower rate of return may well be accepted in exchange for the achievement of other community goals. (p. 316)

Antinori and Bray (2005) also described the Mexican community-based forest enterprise (CFE) as a "social firm", which they defined as follows:

> . . . a business based on collective ownership or secured access to a forest resource by a community, with governance derived from or influenced by local community traditions, where tensions between direct 'democratic' community control and hierarchical management structure are present, and which typically have multiple functions with profits as only one of many goals. (p. 1534)

Antinori and Bray (2005) went on to describe the specific goals of Mexican CFEs, which can broadly be seen as objectives that benefit the community members, as "(a) employment (wages and benefits), (b) public goods investments in community infrastructure and social welfare programs, (c) profit sharing, and (d) capital investments."

Like the "social enterprises" described by Soviana (2015) and the "social firms" described by Antinori and Bray (2005), Chinese SOFEs involve local stakeholders and community members in decision-making and "democratic management" (Const. P.R.C. Art. 16). Also, there is a similar "collective ownership", with forest in China being owned by the "whole people" of that country (Const. P.R.C. Art. 9). Still, there may be differences in ownership and governance between state-owned enterprises on the one hand, and community-based and social enterprises on the other (Peredo and Chrisman, 2006).

For our research on changes in technical efficiency, the relevance of the ownership and governance is that it affects the forms of investment/inputs, and the objectives/outputs (Bozec et al., 2003; Aharoni, 2000). The firm's owner determines the types and quantities of investment or input and the state-owned enterprise uses these to generate the desired objectives or outputs. In the case of community-based enterprises, the owners are community members collectively. In the case of state-owned enterprises, the owner is the central government. Thus, to truly understand the efficiency of SOFEs in these terms, it is necessary to take the perspective of the central government. In the case of the SOFEs, the Chinese central government allocates land and central government funding to each SOFE. The SOFE then uses these inputs to generate the outputs or objectives. Chinese SOFEs share similar types of non-profit, community-benefit oriented objectives with social enterprises and CFEs. These objectives of Chinese SOFEs are apparent in the direction of the government to the SOFEs to "improve forest resource quality", "maintain and enhance ecological functions", and "[improve] people's livelihoods" (State Council, 2015).

For our purposes, we classify the objectives of "social firms", including SOFEs, using the concept of three domains or areas of sustainable development attributed originally to Passet (1979) and

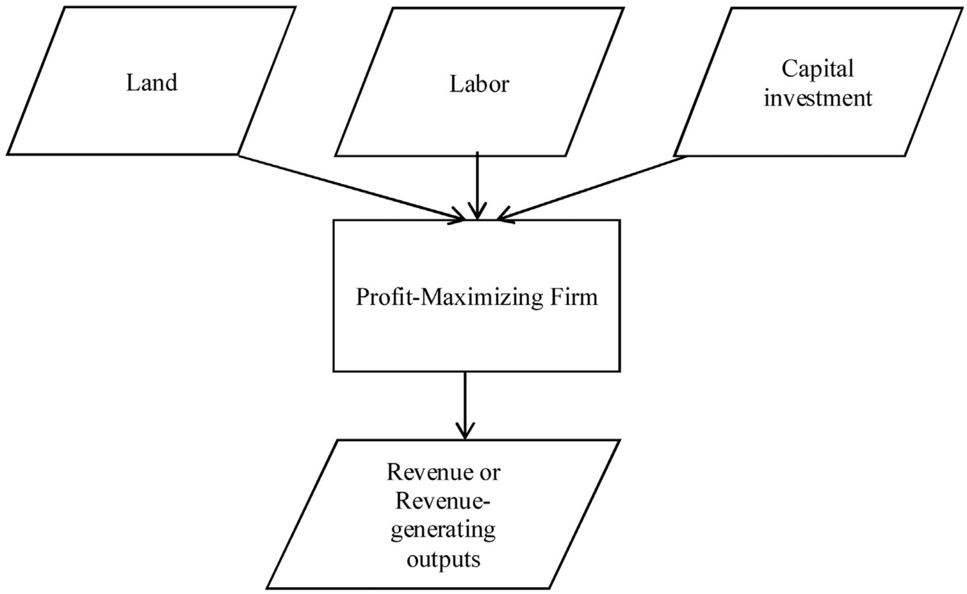

Fig. 2. Generic inputs and outputs of a profit-maximizing firm.

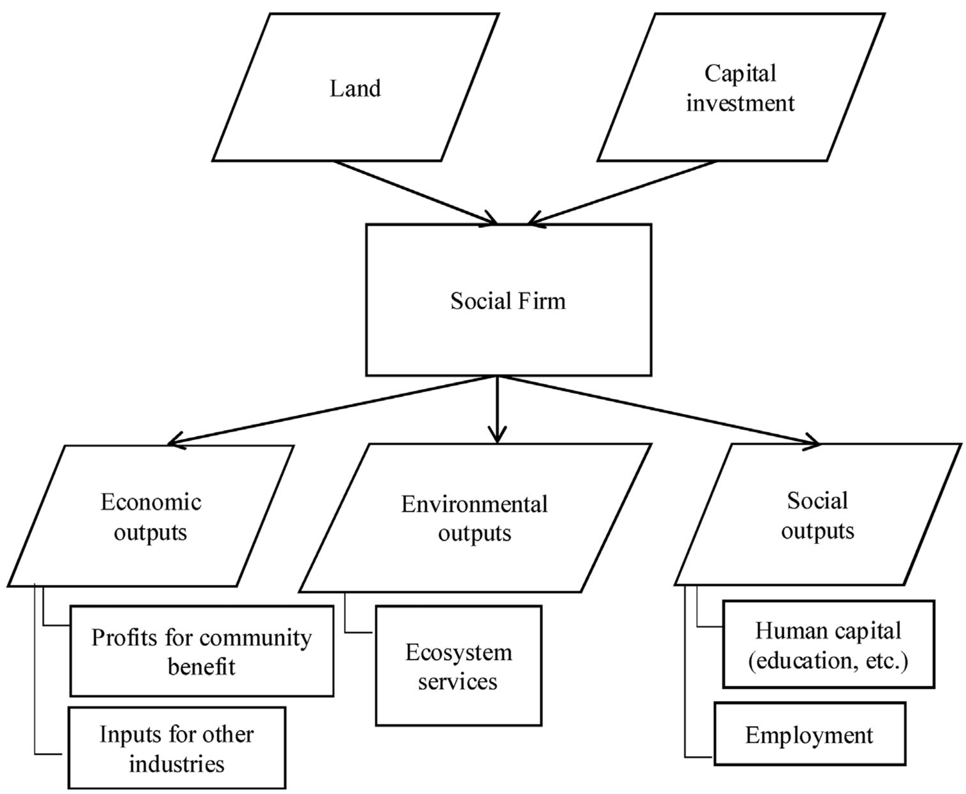

Fig. 3. Generic inputs and outputs of a social firm. The outputs listed are intended as examples, and may not be comprehensive.
Source: Authors.

popularized in Brundtland (1987): economic, environmental, and social. For the purposes of DEA, it is necessary to more specifically describe the types of outputs that might qualify as the economic, environmental, and social outputs. In Fig. 3, we outline how one might view the inputs and outputs of such a social firm, in a generic sense. In the economic area, we propose that profits may be one desired output, as these profits may be divided among community members or invested in community infrastructure like schools, roads, or health care (Antinori and Bray, 2005; Stoian and Donovan, 2010). In addition, "social firms" including CFEs or SOFEs may provide inputs into other important regional industries, such as to supply domestic demands for wood. In the environmental area, social firms may seek to supply ecosystem services such as clean air, water, and biodiversity (Sharma et al., 2017; Burney et al., 2015). It is clear that natural disasters such as the 1998 flooding (see "Historical Perspective of Chinese SOFEs" above) caused the Chinese government to prioritize watershed protection. In the social area, one social objective may be the building of human capital through education and training, and though the involvement of marginalized groups (Stoian and Donovan, 2010). Finally, the contributions of social firms to local employment and people's livelihoods is crucial, as has been widely cited in the literature on CFEs (Charnley and Poe, 2007; Carías Vega and Keenan, 2016; Burney et al., 2015; Stoian and Donovan, 2010; Sharma et al., 2017). While the literature on state-owned enterprises is not as rich as the literature on the objectives of CFEs, in the case of China, it is clear that the government sees its role as "[creating] conditions for employment" (Const. P.R.C Art. 42), with state-owned enterprises as one vehicle to do so.

Methods

Study Area and Data

The study area of northeast China includes Heilongjiang Province, Jilin Province, and Inner Mongolia Autonomous Region (Fig. 4). This region stretches across a long distance east to west, and has long winters, low average temperatures, low precipitation, and relatively infertile soils. Therefore, these areas are support mainly trees that are more resistant to cold weather, such as Dahurian larch (*Larix gmelinii*), Scots pine (*Pinus sylvestris*), and Korean pine (*P. koraiensis*), which have long growth cycles. After years of extensive logging, fire-prone birch species have become established in large numbers.

There are total 86 SOFEs in this study area (excluding Dailing Forest Experimental Bureau). All SOFEs have been going through a general period of overall reform, which includes the NFPP. However, 5 SOFEs also underwent a specific pilot tenure reform. Data on SOFE management for the period of 2003–2009 came from forest statistical yearbooks, annual publications compiled the SFA according to forest documents and information provided by provincial forest administrations. Data categories include forest ecological construction, industrial development, employees and wages, government investment, timber production, forest area and management, etc. Monetary values in Chinese yuan renminbi were adjusted for inflation to real 2014 terms using the Consumer Price Index for Rural Households (National Bureau of Statistics, 2017).

Inputs and Outputs

DEA is a comparison of input and output levels among firms. There are several important differences between the input and output classification of a hypothetical profit-maximizing firm in Fig. 2 and a hypothetical social firm in Fig. 3. First, and perhaps most importantly, a profit-maximizing firm would consider labor to be a cost, or input of production, whereas for a social firm, labor creates employment, which is viewed as a benefit, or output. This has important implications in the measurement of efficiency since a profit-maximizing firm will seek to minimize labor costs but a social firm will seek to increase employment. Second, a profit-maximizing firm will be ambivalent towards social outputs such as amenities, goods, and ecosystem services that accrue to the surrounding community but which they cannot sell. Some profit-maximizing firms are willing to produce benefits for the community if the cost is relatively small, but they would not be viewed as primary outputs. A social firm, however, would view these as important outputs.

Based on these frameworks of profit-maximizing and social firms, and data availability, we modeled the technical efficiency of SOFEs using input and output variables representing the key categories in Figs. 2 and 3. Based on our review of the data, some variables were not consistently reported, or were replaced by other measures over time. Also, some categories were not directly measured. For instance, in the environmental outputs category (Fig. 3), there are few measures of ecosystem services. One variable related to wildlife was not measured before 2006, so we could not use it to compare efficiencies before and after 2006. Therefore we used area of afforestation and area of forest tending as proxies for ecosystem services under the assumption that more and better managed forests will provide more ecosystem services. Also, the government investment variable was measured differently after 2011 so that the pre- and post-2011 government investment data are not comparable, so we restricted our time series to 2003-2009. A description of the input and output variables follows, and Figs. 5 and 6 show the categorization for comparison to Figs. 2 and 3.

For the profit-maximizing framework, the inputs and outputs were selected based largely on the past studies that implicitly followed those assumptions (Liu and Yu, 2006; Zhu and Jing, 2011; Zheng and Wan, 2013; Wang and Zhu, 2013), in order to achieve relative consistency with those studies and allow us to compare our social firms framework to the closest approximation of the profit maximization framework that would be otherwise used. The inputs were (1) AREA – area of forest resource protection[3] (in thousands of hectares), (2) REAL CAPITAL – fixed capital investment,[4] adjusted for inflation (millions of 2014 yuan renminbi), and (3) EMPLOY – total number of full-time employees. Fixed-capital investment includes central government investment, local government investment and bank loans. The output was (1) REAL OUTPUT – the inflation-adjusted total production value[5] (millions of 2014 yuan renminbi).

For the social firm framework, the inputs selected were: (1) AREA, and (2) REAL INVEST – central government real investment (millions of 2014 yuan renminbi). The choice to use the more narrow measure of central government real investment rather than total fixed capital real investment (as in the profit-maximizing framework) has to do with the fact that, as described above (Background, "Social Firms" and the Chinese SOFE Context), our social firms framework takes the perspectives of the firms' owner, the Chinese central government. The central government allocates money and land to the SOFE, which is the central government real investment. This is the only investment that is relevant to the central government as an input. The SOFE manager(s) then may leverage this to obtain additional funds from the local government or banks, but this other additional funding comes from other sources and does not impact the central government's financial account. This additional funding would be seen positively by the central government because it would allow for greater production of outputs, without requiring additional input from the government's perspective.

The outputs of the social firm framework included economic, environmental, and social indicators. They were selected based on an understanding of the history and stated objectives of SOFEs, and constrained by availability of data variables. The economic output was (1) TIMBER – timber production (thousands of cubic meters) – used to supply China's forest products industry. Fig. 3 also includes the possibility of "profits for community benefit" as an economic output of social firms; however, in the case of Chinese SOFEs, those profits would be mainly distributed as wages to workers, which we include as a social output. The environmental outputs were proxies for greater ecosystem services: (2) AFFOR – afforestation[6]

[3] Total area of the state-owned forestland under jurisdiction of the SOFE.

[4] Includes investment in infrastructure, including renovations.

[5] Includes value of timber and non-timber forest products, added value of processed wood, and forest-based service income such as ecological tourism.

[6] Total area of land that is planted with trees in a given year. There were initially some questions about the recording and quality of the afforestation data. For this reason, we conducted the analyses twice: once with afforestation, and once without. We noted no major differences in results between the two analyses, so opted to report only those utilizing the full set of variables, including afforestation. Results excluding afforestation variable are included in an online appendix.

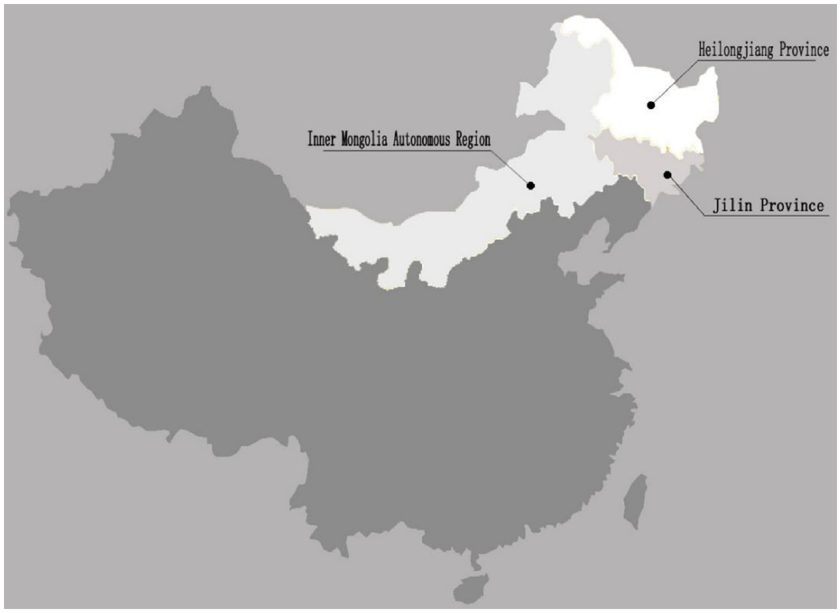

Fig. 4. Map of the study region of northeast provinces of Heilongjiang Province, Jilin Province and Inner Mongolia Autonomous Region.

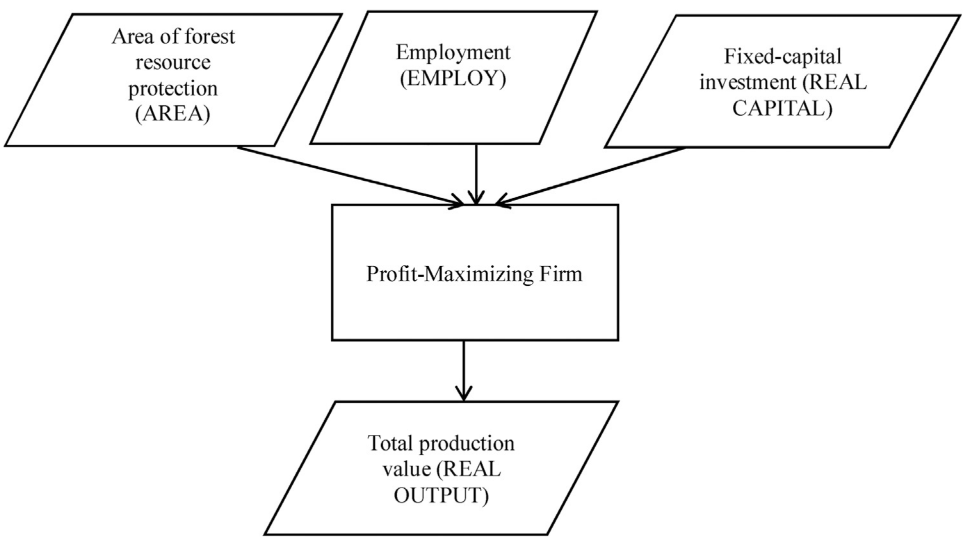

Fig. 5. Data variables used as the inputs and outputs of SOFEs in the profit-maximization framework data envelopment analysis.

(hectares) and (3) TEND – forest tending[7] (hectares). In the social outputs category, employment of local people is clearly seen as a positive. It would have been beneficial to have some other indicators of development of human and social capital, but these were not available in the data. So we proxied contribution to livelihoods by the average wage rate of employees. This gave us: (4) EMPLOY, and (5) REAL WAGE – average annual real wage[8] (2014 yuan renminbi).

Data Envelopment Analysis

We used a data envelopment analysis module in Stata (Ji and Lee, 2010) to estimate relative technical efficiencies. Over the past 35 years, DEA has emerged as one of the primary methods of measuring relative technical efficiency (Charnes et al., 1978; Banker et al., 1984; Coelli et al., 2005; Cooper et al., 2011). A comprehensive description of the methodology is not restated here.

DEA uses linear programming to find shadow prices that maximize the firm's estimated technical efficiency, under the constraint that with the same shadow prices none of the other firms, or linear combinations of the other firms, can pass 100% efficiency. The "CRS" DEA model (Charnes et al., 1978) assumes constant returns to scale, whereas the "VRS" model (Banker et al., 1984) allows variable returns to scale. For an intuitive grasp of DEA, the reader may refer to Fig. 7, which presents a graphical example of a one-input, one-output analysis with four firms. In practice, the VRS efficiency is thought to represent efficiency in utilizing best production practices at a given scale size, whereas the CRS efficiency includes production practices as well as efficiency in scale size (i.e. economies/diseconomies of scale). By using the CRS and VRS models in concert, we can determine what portion of the total (CRS) technical efficiency is due to suboptimal production practices (VRS), and what portion is due to suboptimal scale (scale efficiency = CRS efficiency/VRS efficiency).

[7] Land area in which active silvicultural activities take place.
[8] Total wages paid divided by total number of employees.

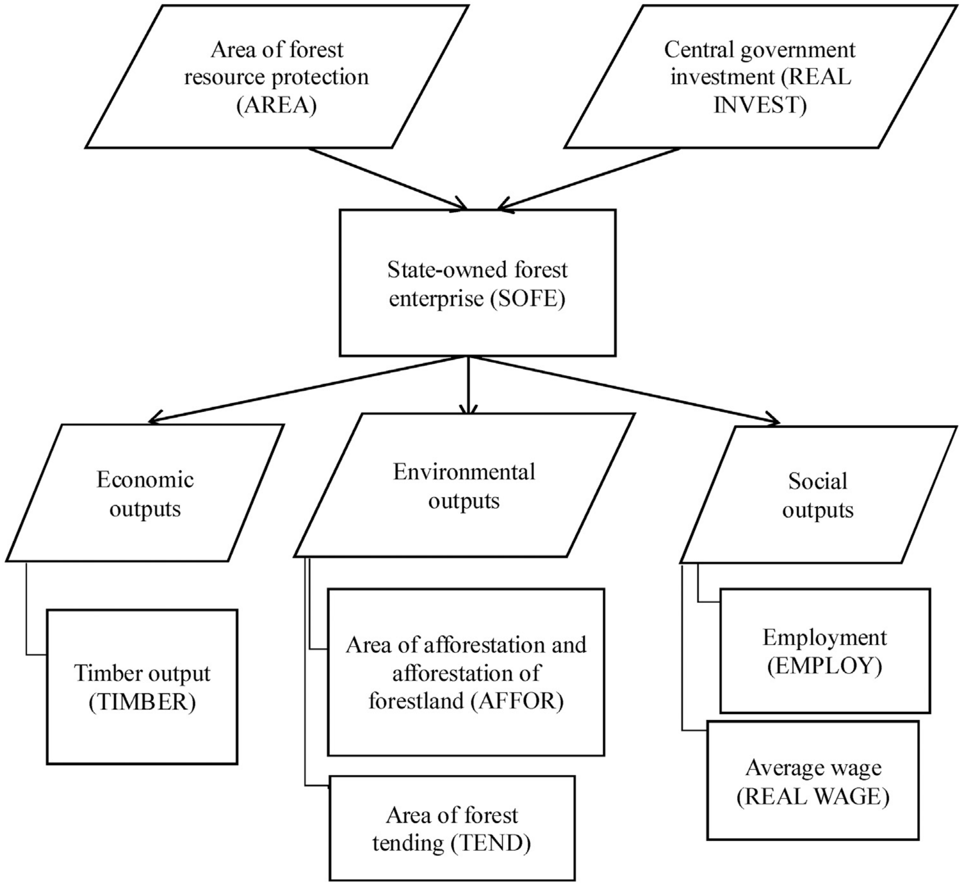

Fig. 6. Data variables used as the inputs and outputs of SOFEs in the social firms framework data envelopment analysis.

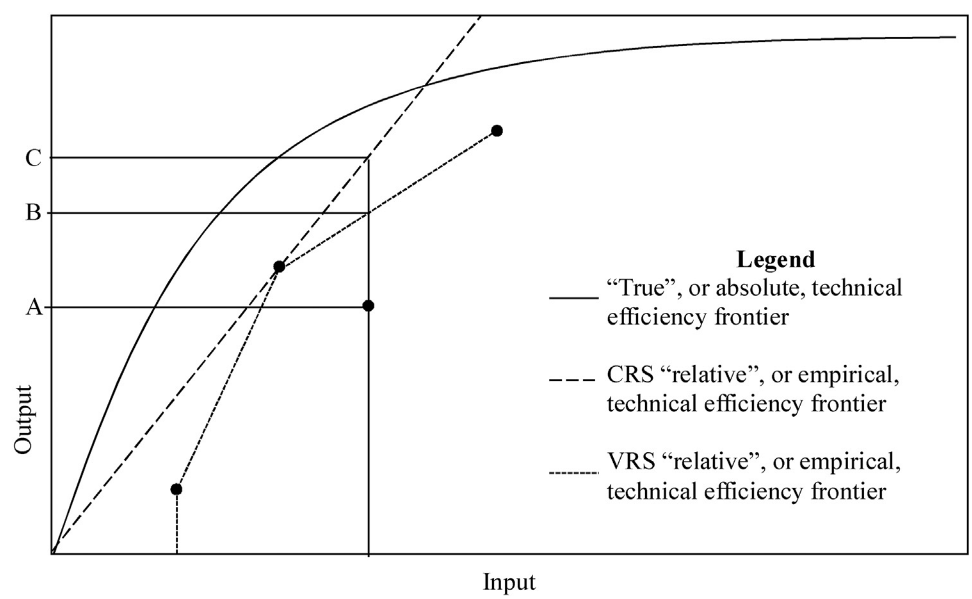

Fig. 7. Depiction of CRS and VRS efficiency in a one-input, one-output example. Each of the four dots represents one firm. The solid curved line represents a hypothetical "true", or absolute, efficiency frontier, which is not measured by DEA. The dashed and dotted lines represent the "relative", or empirical, CRS and VRS frontiers, respectively. The firm that lies on both the dotted and dashed frontiers is efficient in CRS, VRS, and scale efficiency measures. The two firms on the dotted, but below the dashed frontier are efficient in the VRS efficiency measure, but inefficient in scale efficiency, creating inefficiency in the "total technical efficiency" CRS measure.
Consider the firm in the figure that falls below the VRS and CRS frontiers. In an output-oriented DEA, the CRS efficiency is the ratio of A–C. The VRS efficiency is the ratio of A–B. The scale efficiency is the ratio of B–C. Firms using technologies with multiple inputs and/or outputs, such as Chinese SOFEs would be plotted in a multi-dimensional space. The empirical efficiency frontier would be a plane or hyperplane.

The CRS and VRS models can both be formulated with output- or input-oriented approaches. The output-oriented approach maximizes output at a given level of input, while the input-oriented approach minimizes input for a given level of output. We chose to use the output-oriented measure because SOFEs are given a relatively fixed level of inputs (principally land area and government investment), and then seek to maximize outputs based on those inputs. We used the inverse of the standard output-oriented efficiency measure (which goes from 1 to infinity) to generate a more intuitive efficiency score from 0 to 1 (1 is most efficient).

Mathematically, the output-oriented CRS model is given by:

$$\begin{aligned}
&\max_{v_j, w_i} E_0 = \sum_{i=1}^{I} w_i \cdot y_{i0} \\
&s.t. \\
&\sum_{j=1}^{J} v_j \cdot x_{j0} = 1 \\
&\sum_{i=1}^{I} w_i \cdot y_{in} - \sum_{j=1}^{J} v_j \cdot x_{jn} \le 0; \forall n = 1, \ldots, N \\
&w_i, v_j \ge 0; \forall i = 1, \ldots, I; \forall j = 1, \ldots, J
\end{aligned} \tag{1}$$

Where x_j are production inputs; y_i are outputs; v_j and w_i are shadow prices; E_0 is the relative technical efficiency score of enterprise 0, N is the total number of enterprises in the sample. The CRS model (1) above is repeated N times with each enterprise taking the place of enterprise 0 to generate an efficiency score for each enterprise. Similarly the BCC model is given by:

$$\begin{aligned}
&\max_{v_j, w_i} E_0 = \sum_{i=1}^{I} w_i \cdot y_{i0} - w_0 \\
&s.t. \\
&\sum_{j=1}^{J} v_j \cdot x_{j0} = 1 \\
&\sum_{i=1}^{I} w_i \cdot y_{in} - \sum_{j=1}^{J} v_j \cdot x_{jn} - w_0 \le 0; \forall n = 1, \ldots, N \\
&w_i, v_j \ge 0; \forall i = 1, \ldots, I; \forall j = 1, \ldots, J
\end{aligned} \tag{2}$$

DEA does have both strengths and weaknesses relative to other approaches; some of these are described in more detail in Frey et al. (2012). Among the methodology's strengths are the reasons why we utilize it here. Most important is the ability for DEA to incorporate multiple inputs and outputs, some or all of which have no market price or known shadow price. An added benefit is the non-parametric nature of the analysis (i.e. no assumption of functional form). However, we must also be aware of its weaknesses, which if not properly understood can cause misinterpretation of the results. First, DEA uses shadow prices for each input and output, estimated to give the SOFE the highest possible score relative to other SOFEs with the same shadow prices. Thus, an analysis with more inputs and outputs will have more dimensional "space" for individual SOFEs to have higher scores (Hughes and Yaisawarng, 2004; Nunamaker, 1985). Therefore, a DEA with more variables (inputs and outputs) that results in higher average efficiency scores than another with fewer variables, does not necessarily mean that firms are doing better at achieve the objectives of the first DEA. Second, because the efficiency frontier used in DEA is empirical and based on a linear combination of the best firms in the sample (Coelli et al., 2005), average efficiency scores of a sample only represent the closeness of average firms to the best firms within a sample (Frey et al., 2012). For these two reasons, it is not appropriate to compare DEA scores from two different analyses. However, when approached carefully as described below, comparing DEA scores within a sample can have meaning.

Change in DEA Efficiency over Time

When considering the results of DEA, it is important to remember that it measures efficiency relative to a surface created by linear combinations of other firms (Coelli et al., 2005). That is, DEA measures relative, rather than absolute, technical efficiency. There are several factors that influence the efficiency of SOFEs, such as forest resources, topography, geology, climate, geography, capital, labor, management, technology, policy, and institutions. Many of these factors are beyond the control of individual SOFEs and do not change over time. For example, a particular SOFE might be in a colder climate or more mountainous terrain, or could be located further from markets, all of which could negatively affect its efficiency score. For this reason, a head-to-head comparison of the efficiency of two different SOFEs is not always an appropriate comparison. By estimating the change in efficiency of individual SOFEs over time, we control for these SOFE-specific, unchanging factors constant (Fraser and Cordina, 1999; Luo, 2003). Then, by comparing these changes across different groups, we can control for macroeconomic and technology factors that change over time, but affect all SOFEs.

We use two approaches, which calculate slightly different measures, both of which are appropriate, to look for changes in SOFE efficiency over time, by groups. The first approach is to use a non-parametric Wilcoxon signed-rank test of paired comparisons to compare efficiencies of individual SOFEs at two points in time (Fraser and Cordina, 1999; Luo, 2003). In order to correctly evaluate a change in efficiencies over time with the Wilcoxon signed-rank test, we pooled the multiple years of data into a single DEA set. This is because DEA measures efficiency only up to an empirical boundary created by the most efficient firms in any particular set (Frey et al., 2012).

The second test we used for changes in efficiency over time is a test for shifts in the efficient frontier as described by Sowlati (2007). In this methodology, we first conduct DEA of all SOFEs in each single year. We then project inefficient SOFEs to the efficient frontier, and run a pooled DEA of two or more years of the projected SOFEs. A Wilcoxon rank-sum (Mann-Whitney U) test (for two years) or Kruskal–Wallis (for three or more years) is used to determine if the efficient frontier has shifted.

Returns to Scale

Based on the VRS efficiency, DEA can tell us if a particular firm is operating in a place in the production possibilities frontier where there is increasing returns to scale (IRS) or decreasing returns to scale (DRS) (Banker et al., 1984). If under IRS, the firm can increase its scale efficiency by increasing the level of inputs, and similarly by decreasing inputs if operating under DRS.

Impact of Pilot Forest Tenure Reform

Since we calculated efficiency scores (CRS, VRS, and Scale) for all 86 SOFEs over four years, we have a panel spanning before and after the 2006 pilot tenure reform, which we exploit to estimate the impact of the pilot reform. We estimated a random-effects tobit model of the form

$$\begin{aligned}
E^*_{k,t} &= \beta_0 + \beta_1 \cdot t + \beta_2 \cdot YICHUN + \beta_3 \cdot REFORM \\
&+ \beta_4 \cdot REFACT + \upsilon_k + \varepsilon_{k,t}
\end{aligned} \tag{3}$$

Where $E^*_{k,t}$ is a latent variable for the efficiency score $E_{k,t}$ that is truncated at 0 and 1.

$$E_{k,t} = \begin{cases} 1 \; if E^*_{k,t} > 1 \\ E^*_{k,t} \; if 0 \le E^*_{k,t} \le 1 \\ 0 \; if E^*_{k,t} < 0 \end{cases} \tag{4}$$

Where the indices k and t represent the particular SOFE and the year of measurement. YICHUN and REFORM are 0, 1 dummy variables representing if the SOFE is in Yichun municipality, and if the SOFE is in the group of tenure reform pilots (dummy is 1 both pre and post reform). REFACT is a dummy for the group of tenure reform pilots, which is 1 only in the years after the 2006 reform. The coefficient β_4 for the dummy REFACT measures the impact of the actual piloted reform on the latent efficiency score.

This formulation is essentially identical to the standard difference-in-differences estimator (see: Meyer, 1995), with the additional steps of (1) controlling for differences between SOFEs within and outside Yichun city, and (2) using a tobit form to truncate the values at 0 and 1. The difference-in-differences estimator is designed to control for endogeneity such as selection bias, trends in outcomes, etc. (Meyer, 1995). By including the dummy variables YICHUN and REFORM, in addition to the nature of the panel model, we control for the fact that the pilots were only in Yichun city, and that the pilots may not have been selected randomly. Any differences between Yichun SOFEs and other northeast SOFEs, and any differences between the Yichun pilot reform and Yichun non-reform SOFEs would be factored out of the impact of REFACT.

There still is the concern that there may be other interaction effects besides the pilot reform that are not measured, so the non-reform group should be as similar as possible to the treatment group (Meyer, 1995). We note that the most logical comparison is between the SOFEs in Yichun, which is why we include a control dummy for Yichun. Second, Wan and Geng (2009) noted that a principal reason for piloting the tenure reform was low wages before the reform. Therefore, comparison SOFEs should have similarly low wages before the reform. We verify this in the Results Section (Inputs and Outputs).

Results

Inputs and Outputs

The entire dataset used for this analysis can be downloaded from Appendix A, Supplemetatry data. Table 2 presents the summary statistics of the input and output variables for the entire set of 86 SOFEs, for the five SOFEs in the Yichun municipality that underwent tenure reform in 2006, and for the 11 SOFEs in Yichun that did not undergo tenure reform. In terms of the inputs, the physical area of the SOFEs held relatively constant over time, with some minor variation. However, the central government investment and fixed capital investment increased significantly from 2003 to 2009. That investment trend may not continue due to the economic and political environment.

In terms of outputs, there were several different trends. Timber production held relatively constant over time from 2003 to 2009. This is likely due to stringent annual harvest limits (quotas) set by the central government. The central government formulated minimum reforestation levels for every SOFE each year, with the goal of achieving forest growth rates that increase or remain stable. Due to a decline of investment from 2003 to 2005, forest tending and afforestation both had a marked decrease during 2005. Still, both forest tending and afforestation generally tended to increase over time, although afforestation did not consistently increase every year. Employment decreased over time, while the

Table 2
Means and standard deviations for input and output data for 86 SOFEs, for the subset of 5 SOFEs in Yichun that underwent pilot forest tenure reform in 2006, and for the subset of 11 SOFEs in Yichun that did not undergo forest tenure reform.

			Area Thousands of hectares	Real invest Millions of 2014 CNY	Real capital Millions of 2014 CNY	Employ Employees	Real wage 2014 CNY	Timber Thousands of m^3	Affor Hectares	Tend Hectares	Real output Millions of 2014 CNY
All Northeast SOFEs	2003	Mean	310.2	5.2	66.5	5966	7112	121.4	467	3941	349.0
		(St. dev.)	(209.7)	(2.8)	(37.7)	(2570)	(2034)	(74.4)	(451)	(2476)	(185.2)
	2005	Mean	310.6	4.0	52.4	5469	7782	121.5	42	3879	384.9
		(St. dev.)	(209.2)	(1.7)	(27.8)	(2179)	(2449)	(79.1)	(138)	(2428)	(209.6)
	2007	Mean	319.6	5.6	80.7	4888	10,831	121.5	313	4125	456.6
		(St. dev.)	(223.1)	(3.0)	(49.1)	(2065)	(3331)	(82.3)	(642)	(2762)	(246.9)
	2009	Mean	317.5	8.0	140.2	4116	14,231	117.7	272	4123	556.9
		(St. dev.)	(205.3)	(3.1)	(75.8)	(1757)	(4419)	(73.9)	(850)	(3288)	(366.2)
Yichun pilot tenure reform SOFEs	2003	Mean	142.2	4.3	45.5	6219	5521	50.7	557	2021	422.2
		(St. dev.)	(38.2)	(0.8)	(8.8)	(1436)	(794)	(20.9)	(214)	(1024)	(93.8)
	2005	Mean	142.2	3.5	40.7	5616	5821	44.4	0	2021	443.0
		(St. dev.)	(38.2)	(0.6)	(7.3)	(1520)	(578)	(16.4)	(0)	(1024)	(145.0)
	2007	Mean	132.4	9.0	94.4	5046	10,935	45.9	90	3283	593.0
		(St. dev.)	(43.7)	(4.8)	(48.1)	(1368)	(907)	(17.2)	(202)	(2699)	(142.7)
	2009	Mean	132.1	8.2	180.7	4537	13,150	47.6	27	2763	851.6
		(St. dev.)	(25.0)	(2.5)	(72.9)	(1278)	(2358)	(18.1)	(59)	(2987)	(145.3)
Yichun non-reform SOFEs	2003	Mean	218.0	4.8	52.0	8125	4798	98.4	776	3928	549.2
		(St. dev.)	(57.6)	(0.9)	(8.8)	(3383)	(1182)	(57.6)	(401)	(1818)	(189.8)
	2005	Mean	218.0	3.5	40.6	7445	4977	92.6	0	3928	606.0
		(St. dev.)	(57.6)	(0.7)	(8.4)	(3062)	(1270)	(53.2)	(0)	(1818)	(224.7)
	2007	Mean	217.7	7.6	80.5	7086	9022	97.7	95	4438	722.7
		(St. dev.)	(58.0)	(2.3)	(24.4)	(2345)	(1192)	(56.7)	(180)	(1985)	(288.9)
	2009	Mean	212.4	9.7	202.9	6217	11,120	100.2	49	4383	1060.8
		(St. dev.)	(57.5)	(3.8)	(117.1)	(1815)	(1628)	(57.8)	(110)	(1855)	(444.9)

real wage tended to increase. Generally, an increase in government investment appears to be positively related to forest tending and wage.

Overall, the SOFEs in Yichun (Table 2) tended to be smaller than the average SOFEs in terms of forest land area and timber production, but received similar levels of government investment. Trends in the variables were similar to the trends in the overall sample, but more uneven. The wage rate and government investment level in Yichun before 2006 was lower than the overall average, but was similar to or higher than the overall average after the reform.

Comparing the pilot reform and non-reform SOFEs in Yichun only (Table 2), we note that pre-reform (before 2006), the non-reform SOFEs were somewhat larger in terms of forest land area, government investment, timber production, and employment than the reformed SOFEs. It is important to note that, other than being located in Yichun, low wages may have been one of the drivers of the reform. The to-be-reformed SOFEs actually had somewhat higher real wages pre-2006 than the non-reformed Yichun SOFEs, so comparisons between the reform and non-reform Yichun groups are reasonable.

Data Envelopment Analysis

We used the input and output data in Appendix A, Supplementary data (summarized in Table 2) to estimate three efficiency measures (CRS, VRS, and Scale) for each SOFE in each year, with an output-oriented DEA. We conducted this using the social firms framework and the profit-maximization framework for classifying inputs and outputs, in order to compare our new conceptual framework to that implicitly used in past research. We pooled the data for all SOFEs and all years when calculating the efficiency scores, but report the results by year, for all northeast SOFEs, Yichun reformed, and Yichun non-reformed in Table 3. An initial reading shows that average CRS "total" technical efficiency was around 0.65 for the social firms framework, and 0.39 for the profit-maximization framework during the four years analyzed. One must be very careful with the interpretation of these "average" results. This does not necessarily mean that an average SOFE could vastly increase its production without increasing inputs, or that SOFEs do a better job as social firms than as profit-maximizers. First, one must remember that the DEA measure of efficiency is simply a measure of efficiency relative to other firms. Second, many factors affecting this efficiency are out of the control of the SOFEs. Since many SOFEs have unchangeable constraints that affect efficiency (e.g., geographic, topographic, demographic, climatic, and soil factors), we cannot directly compare one SOFE to another. The principal relevant comparisons we can make are to compare changes in efficiencies of individual SOFEs over time. Third, dimensionality of the inputs and outputs affects the calculation. This is likely the reason that the social firms analysis provides higher average scores than the profit-maximization analysis. In any event, averages of DEA scores should only be viewed as measures of heterogeneity, not of overall efficiency (Frey et al., 2012).

Change in DEA Efficiency over Time

For the set of all SOFEs, we used a paired Wilcoxon signed-rank test of individual SOFEs compared to themselves in different years, and a Wilcoxon rank-sum/Kruskal–Wallis test of the annual sets of efficient frontier-projected SOFEs (Sowlati, 2007) to determine if there were significant changes in efficiencies over time. Statistically significant differences between years are indicated by the superscript letters (paired Wilcoxon signed-rank) and superscript numbers (frontier-projected Wilcoxon rank-sum) in the "All" SOFE columns. SOFEs have been the subject of numerous policy reforms and programs starting in the 1980s, accelerating since 1998. If these

Table 3
Average "social firm" efficiency scores, using output-oriented measure for 86 SOFEs, 5 Yichun pilot reform SOFEs, and 11 Yichun non-reform SOFEs.

		CRS			VRS			Scale		
		All	Yichun Pilot Reform	Yichun Non- Reform	All	Yichun Pilot Reform	Yichun Non- Reform	All	Yichun Pilot Reform	Yichun Non- Reform
Social firm frame-work	2003	$0.66^{b:1}$	0.73	0.73	0.76^{a}	0.77	0.77	0.87^{b}	0.95	0.95
	2005	$0.72^{a:1}$	0.76	0.80	0.78^{a}	0.78	0.84	0.92^{a}	0.98	0.96
	2007	$0.66^{b:1}$	0.65	0.59	0.78^{a}	0.76	0.76	0.83^{b}	0.84	0.78
	2009	$0.55^{c:2}$	0.63	0.52	0.76^{a}	0.75	0.77	0.74^{c}	0.85	0.69
Profit-maximi-zation frame-work	2003	$0.34^{c:2}$	0.53	0.53	0.40^{b}	0.61	0.58	0.88^{b}	0.91	0.91
	2005	$0.42^{a:12}$	0.62	0.67	0.47^{a}	0.64	0.70	0.90^{a}	0.96	0.95
	2007	$0.41^{ab:1}$	0.58	0.57	0.49^{a}	0.60	0.66	0.85^{bc}	0.94	0.87
	2009	$0.38^{b:12}$	0.63	0.58	0.47^{a}	0.67	0.72	0.83^{c}	0.93	0.81

[a,b,c]– Superscript letters in the "All" column represent statistical equivalence within framework and efficiency type at 0.01 alpha-level, using a paired Wilcoxon signed rank test. That is, values marked with an "a" are not statistically different from other values marked with an "a" in the same framework and efficiency type. [1,2,3]–Superscript numbers in the "All" column represent statistical equivalence within framework at 0.01 alpha-level, using a frontier-projected Wilcoxon rank-sum test (Sowlati 2007). Only applied to the CRS efficiency. That is, values marked with an "1" are not statistically different from other values marked with an "1" in the same framework.

changes and reforms are having a positive effect on China's state-owned forests, we would expect to see efficiency increasing over time. For example, efficiency scores in 2009 should be consistently higher than those in 2003. We would expect this to be especially true the "social firm" framework since SOFEs are directed to generate social benefits (State Council, 2015), and for the VRS efficiency which is related to optimal production practices. Subsequently the CRS efficiency is composed in part by the VRS efficiency. Scale efficiency may be more difficult to change since SOFEs may not be so easily able to change land area; however, increasing or decreasing the amount of investment or employment could affect the scale size.

Despite the stated objectives of SOFEs, the results (Table 3) indicate that SOFEs in general showed much more improvement over time in the profit-maximization than in the social firms framework measure. In the social firms framework measure, the CRS (overall) efficiency generally decreased within SOFEs from 2003 to 2009. CRS efficiency was at its overall highest during 2005, and its lowest during 2009. Decomposing the social firms framework CRS (total) efficiency, we see that the VRS (optimal production practices) held steady from 2003 to 2009. On the other hand, scale efficiency decreased, and was the driver of the decreases in overall CRS efficiency from 2003 to 2009.

In the social firms framework, the steady VRS efficiency provides us no evidence that reforms have led to more production of social outputs at lower cost. This steady VRS efficiency, in combination with decreases in scale efficiency, lead to decreasing CRS (total) efficiency. Thus, the overall impact of any reforms has not led to an increase in CRS (total) efficiency over the period we measured.

On the other hand, the firms did show significant increases in profit-maximization framework measures over time. Profit-maximization CRS ticked up between 2003 and 2007. Decomposing this result, we see that this was due to a marked increase in VRS efficiency from 2003 to 2005 that held steady afterwards, and a more inconsistent decline in scale efficiency over the period. The decline in scale efficiency is the one consistent factor between the social firms and profit-maximization frameworks. This will be explored in more detail in the next section.

Returns to Scale

As noted, the SOFEs, and in particular the 81 non-tenure-reform SOFEs, tended to decrease in scale efficiency over time (Table 3). This was true in both the profit-maximization and social firms framework scale efficiency measures. Table 4 shows the percentage of each group of SOFEs operating in areas of the production function where there are IRS and DRS. Interestingly, nearly one in five SOFEs were operating under IRS in 2003 and 2005, that is, they were too small. This proportion decreased greatly from 2005 to 2009. On the other hand, the proportion of SOFEs under DRS increased from 2005 to 2009. Taken together, these two trends, along with the overall decrease in scale efficiency indicate an overall increase in scale of SOFEs, but not to their advantage. These trends hold for both the social firms and profit-maximization frameworks.

These findings are reflected in the summary statistics for inputs (Table 2), which shows relatively stable land area but vastly increasing government investment. For example, mean real government investment approximately doubled from 2003 to 2009. At the same time, outputs did not increase in proportion – while total production value, wages, and forest tending did increase substantially, timber, afforestation, and employment did not. While some increase in scale from 2003 seems to have been justified for the 20% of SOFEs under IRS, it appears that over the period, many SOFEs may have surpassed the optimal scale size. The Chinese government determined scale of SOFEs not according to operational efficiency, but based on natural and human factors (Liu and Yu, 2006), presumably choosing to obtain greater levels of output even if these outputs are not produced at an efficient level. For example, it is clear that the government prioritizes environmental outputs such as watershed protection (proxied by afforestation and forest tending in our model). Since it is difficult to create new SOFEs at optimal scale, they may simply choose to increase the scale of existing SOFEs, by investing more money in each. In brief, then, the results indicate that the SOFEs were becoming larger (in terms of investment levels) and less efficient over time.

Impact of Pilot Forest Tenure Reform

We estimated tobit panel random-effects models with latent values of CRS, VRS, and Scale efficiency as the dependent variables for both the social firms and profit-maximization frameworks (Tables 5 and 6). This model is essentially a difference-in-differences model. Our panel models included a time trend, denoted by the variable T in Tables 5 and 6. In the social firm framework models, we found that CRS and Scale efficiencies decreased significantly over time, and VRS efficiency had no significant time trend, consistent with the results in Table 3 above. In the profit-maximization framework models, we found that CRS and VRS efficiencies increased over time, and scale efficiency decreased, also consistent with Table 3 results.

The coefficient of the YICHUN dummy represents the average difference between those SOFEs in Yichun and other northeast SOFEs. The coefficient for the REFORM dummy represents the average difference between the reformed and the non-reform Yichun SOFEs, prior to 2006. The coefficient for the REFACT dummy represents the change in efficiency for the reformed SOFEs from before to after 2006, after controlling for the other factors stated. In sum, we found no statistically significant correlation between the implementation of the 2006 pilot forest tenure reform and any efficiency measures. This indicates a lack of evidence that this particular pilot tenure reform has had any impact on efficiency, and held for both the social firms framework and the profit-maximization framework measures. Any possible impact of the pilot tenure reform could not be detected with this small sample size.

Results from the same models, but using only data from the 16 Yichun SOFEs with all variables, and for all SOFEs and only Yichun SOFEs but excluding the AFFOR variable, are presented in online Supplementary Tables 1-5. Even though in the model with the full data set (all 86 SOFEs) we control for the average difference between the Yichun and non-Yichun SOFEs with a dummy variable, the model with only Yichun SOFEs might be preferred since those are the SOFEs that are most similar to the treatment group. Substantively, we found the results are the same regardless of whether we use the full data or only Yichun.

Our results contradict those found by Zhu and Jing (2011), which used an input and output classification framework that closely approaches our "profit-maximization" framework. That research found increasing efficiency among the SOFEs that underwent pilot tenure reform. However, we did not find any statistically significant impact of the pilot, either using the social firms or profit-maximization framework. Our sample is broader both in terms of number of SOFEs and the time period analyzed. Zhu and Jing's (2011) result may be limited because they only use two years. Forest investments and activities are long-term in nature and SOFEs are highly variable. Also, there may be an existing trend in efficiency improvements over time – a two-year model would not be able to differentiate a single increase in efficiency due to a one-time reform from a longer-term trend. By using a longer time period, we are able to include a time trend variable, and factor out longer-term trends. We found no statistical evidence of impact from the 2006 pilot tenure reform on efficiency.

Table 4
Percent of each SOFE group, in each year operating under increasing returns to scale (IRS) or decreasing returns to scale (DRS). Sum of IRS and DRS may not equal 100% because some firms operated at efficient scale.

		IRS			DRS		
		All	Yichun Reform	Yichun Non- Reform	All	Yichun Reform	Yichun Non- Reform
Social firm frame-work	2003	16.3	20	9.1	77.9	80	81.8
	2005	20.9	40	54.6	73.3	60	36.4
	2007	5.8	20	0	82.6	80	100
	2009	1.2	0	0	91.9	100	100
Profit-maximi-zation frame-work	2003	23.3	40	18.2	76.7	60	81.8
	2005	24.4	60	36.4	70.9	40	45.5
	2007	18.6	20	0	77.9	60	100
	2009	18.6	20	0	80.2	80	100

Table 5
Tobit panel random-effects (difference-in-differences) model with latent CRS, VRS, and Scale efficiency values as dependent variable, using "social firms" framework for classification of DEA inputs and outputs.

	CRS		VRS		Scale	
	Coefficient	Std Error	Coefficient	Std Error	Coefficient	Std Error
T	−0.019***	0.004	−0.001	0.003	−0.024***	0.003
YICHUN	0.016	0.047	0.011	0.044	0.008	0.041
REFORM	0.043	0.085	0.001	0.077	0.067	0.074
REFACT	−0.021	0.069	−0.030	0.051	−0.016	0.054
Constant	0.724***	0.023	0.781***	0.019	0.938***	0.019
Sigma u	0.123***	0.013	0.123***	0.012	0.112***	0.011
Sigma e	0.149***	0.007	0.109***	0.005	0.119***	0.006
Wald Chi2	29.29***		0.57		74.03***	

*** Statistically significant at the 0.01 alpha-level.

Table 6
Tobit panel random-effects (difference-in-differences) model with latent CRS, VRS, and Scale efficiency values as dependent variable, using "profit-maximization" framework for classification of DEA inputs and outputs.

	CRS		VRS		Scale	
	Coefficient	Std Error	Coefficient	Std Error	Coefficient	Std Error
T	0.006***	0.003	0.013***	0.003	−0.009***	0.002
YICHUN	0.247***	0.051	0.257***	0.065	0.029	0.040
REFORM	−0.004	0.089	−0.015	0.111	0.030	0.068
REFACT	0.008	0.050	−0.041	0.058	0.042	0.038
Constant	0.321***	0.022	0.363***	0.027	0.897***	0.017
Sigma u	0.148***	0.013	0.189***	0.016	0.115***	0.010
Sigma e	0.108***	0.005	0.126***	0.006	0.082***	0.004
Wald Chi2	36.98***		38.28***		23.90***	

*** Statistically significant at the 0.01 alpha-level.

Discussion

The social firm framework does not assume profit maximization of firms as a the criterion for technical efficiency, but rather utilizing land and government investment levels to produce various social goods, such as employment, ecosystem services, and economic development, which is consistent with the Chinese government's stated goals for SOFEs (State Council, 2015).

From Table 3, we can see that SOFEs showed much more improvement in the profit-maximization than in the social firms measure from 2003 to 2009. To be specific, the CRS (overall) efficiency generally decreased in the social firms framework measure, and the VRS held steady. One possible explanation for this might be that in social firms framework, there are more inputs and outputs that are difficult to manage. Furthermore, environmental changes may be difficult to measure in the short-term due to long forest growth cycles. Effective policies for forest development may need a longer time to demonstrate results. Therefore, for now the results could be relatively difficult to be detected because of various kinds of reasons that are out of control of the SOFEs.

On the other hand, the SOFEs did show increases in profit-maximization framework measures over time. The exact reason why SOFEs are improving in this aspect but not in social outputs is not completely clear, but is related to the increase over time of real output, the inflation-adjusted total production value, which includes value of timber and non-timber forest products, added value of processed wood, and forest-based service income such as ecological tourism. In reality, both the profit-maximization and social firms frameworks may be relevant in certain ways; that is, there may be some underlying tensions that SOFE managers face caused by competing visions for the role of SOFEs in Chinese society. This lack of clarity itself could cause inefficiencies.

The pilot tenure reform was meant to transform forest management by devolving forestland use rights to small groups of households or individuals and by adjusting related forest policies. If these reforms worked as intended, they would bring about major changes to local economy and forest ecosystems (Ho, 2006; Hyde et al., 2003). However, our results provide no statistical evidence to indicate that the SOFEs which piloted forest tenure reform had any increase in efficiency after the time of the pilot reform. This is different from a past study (Zhu and Jing, 2011) that we compared efficiency of SOFEs through the pilot reform, and we believe the difference is due to our decision to use a medium-length time horizon. Further, we classify inputs and outputs using both a social firm and profit-maximization framework.

There is no robust statistical evidence to demonstrate that the pilot tenure reform has influence on efficiency. These results could be explained by several possible factors. First, it may take time to create or rewrite procedures and regulations, and redefine rights and obligations under the new framework. For example, there is a question of compensation for smallholders who suffer economic losses due to logging bans. Such compensation would be difficult to implement while tenure reform is in a state of flux. Second, attitudes and traditions about forest management and governance may be deeply ingrained into northeast forestry area managers and workers. For example, managers may find it difficult to shift their business model from logging to tourism. Third, there may be vested interests and patterns of interest distribution that are difficult to break. Forest tenure reforms require adjustments and may generate redistribution of economic interests. Existing vested interests may fight to keep control of their longstanding benefits.

Government investment appears to be positively related to forest tending and wage. Forest authorities manage the activities of SOFEs using principally investment levels and quotas. However, lack of information about SOFE decision-making processes makes it extremely hard for the government authorities to supervise and assess the SOFEs (Xu et al., 2004a). Therefore, SOFEs tend to obtain capital based only on the number of forest workers, the size of SOFEs, natural conditions, or policies (Liu and Yu, 2006). This limitation, and the fact that government investment varies from year to year because of macroeconomic conditions, constrains the development of the SOFEs (Li et al., 2004).

In April 2014, the Chinese government announced a trial ban on commercial logging in northeast China. Similar bans have been imposed in other regions of China starting in 2000 (Liu et al., 2008). In those cases, workers are reassigned to other tasks or industries, or receive subsidy payments (Liu et al., 2008; Shen et al., 2006). Forest experts have hailed the logging ban as a major policy to enable timber supplies to recover and shift industry's focus towards improved forest management. Zhang Yuxing, Chief Engineer in the State Forestry Bureau, Planning and Design Department has indicated that the trial logging ban is conducive to the recovery growth of forest resources, and plays a bigger role as "green ecological defense". It will also increase timber stocks for the future.

Assuming that some reforms are necessary to improve the operational efficiency of SOFEs, the top-level design of those reforms is a key challenge. A top-level design involves clarifying existing problems in northeast forest area; exploring management objectives and multiple objectives of government, SOFEs, and forest workers; building "win-win" criteria among government, SOFEs, and forest workers; developing diverse management alternatives and implementing decision alternatives; and evaluating the success of SOFEs and Chinese government according to the established criteria and multiple objectives (Lee et al., 2013).

Furthermore, development of a platform for government, SOFEs and forest workers to communicate, negotiate and collaborate on ecological restoration and socioeconomic development in the northeast stated-owned forest area may be a direction for future research. Forest workers are closely linked to forest resources and management. Nevertheless, forest workers have among the lowest standards of living in China, and their salaries appear at the bottom of the list of more than 60 sectors published in the national statistics (National Bureau of Statistics, 2003–2009). There have been power imbalances between interest groups, especially between government and forest workers (Wan et al., 2009). These imbalances may result in lack of cooperation, potentially causing the paralysis of forest policy execution or silent resistance from forest workers.

Conclusions

SOFEs in northeast China play extremely important roles in timber production and ecological construction and security. When the People's Republic of China was established, the SOFEs' main task was to provide raw material for the development of heavy industry. The low weight put on regeneration and sustainability resulted in degradation of the forest. In the late 1970s, northeast SOFEs fell into a situation of "two crises" – ecological degradation and economic loss. A series of reforms has aimed at shifting the goals of forest management from timber production to provision of ecosystem services began in the 1980s and became stronger after 1998. In 2006, a new forest tenure reforms was piloted in five SOFEs in Yichun municipality, Heilongjiang province in northeast China, which has created many small holders in a short period, posing regulatory challenges. In April 2014, the Chinese government launched a strict ban on commercial logging in northeast China.

This research developed new theory about how to measure the success of social firms as illustrated by Chinese SOFEs, which use the area of forest resource protection and central government investment to produce social outputs including timber, afforestation, forest tending, employment, and wages as outputs. The success of Chinese SOFEs at using the land and budget inputs to produce the social outputs was measured with data envelopment analysis, based on data from 86 SOFEs in northeast China. These enterprises may not be profit maximizers, but do still seek to produce as much social goods as possible with their forest area and government investment, so as to generate as much benefit as possible for the community and nation.

DEA is an approach to measuring relative technical efficiency by comparing relative utilization of inputs and production of outputs. We used DEA analysis to assess relative efficiency based on the theory of the social firm, and trends of SOFEs in northeast China, and tested the impact of the piloted forest tenure reform, using data over the period 2003–2009.

This theory and approach allowed us to estimate the technical efficiency of SOFEs from 2003 to 2009. The results of 86 SOFEs in northeast China demonstrate that land area held relatively constant over time, but real government investment increased. In terms of outputs, timber production held steady, while tending and wages seem highly linked to increased government investment. When using a framework that assumes SOFEs are "social firms", we found that VRS efficiency did not change over time and Scale efficiency decreased significantly over time, resulting in a significant, decrease in overall CRS efficiency over time. The lack of change in VRS efficiency fails to provide evidence that the general reform environment since the late 1990s is leading to better management of the natural resources over time for "social" outcomes. However, we also applied a second framework that assumes "profit-maximization". This efficiency measure was increasing over time.

Previous studies also used this implicit "profit maximization" framework (Liu and Yu, 2006; Zhu and Jing, 2011; Wang and Zhu, 2013). In general, when we used a profit-maximization framework, we did find increasing efficiency over time, in line with those past works. However, we challenge this finding based on the fact that SOFEs are directed to provide social benefits (State Council, 2015), making the social firms framework more appropriate for estimating efficiency. Also, our results found no impact of the 2006 pilot tenure reform on efficiency regardless of using the social firms or profit-maxmization framework. This contradicts Zhu and Jing (2011).

Interestingly, the majority of SOFEs were operating under decreasing returns to scale, meaning they were too large, and this got worse over time. Primarily this appeared to reflect the increased government investment that did not produce proportionally higher outputs. Government investment levels were determined not according to operational efficiency but based on natural and human factors.

Since 2006 was a key year in implementing forest tenure reform in the five pilot SOFEs that was spanned by our data, we conducted a tobit panel random-effects model to determine if the reform was correlated with a change in efficiency. The model showed no change in any of the three types of efficiency due to the reform. This lack of finding contradicts Zhu and Jing's (2011) result, but our result should be more robust because of use of the theory of the social firm that should be aligned with SOFEs' true objectives, a broader set of SOFEs, and a longer time period.

In order to achieve sustainable development of the state-owned forest and improve overall productivity, as measured by efficiency, new income streams may help increase employment and wages while lowering reliance on government support. Ecotourism, non-timber forest products and other possible income streams likely will not be sufficient to supplant all the government or timber revenue, but further research could explore this non-timber economy and the types of institutional systems that can support it.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jfe.2018.02.002.

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