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Factors associated with harvest and postharvest loss among soybean farmers in Western Paraná State, Brazil

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ABSTRACT

The United Nations included reducing harvest and postharvest losses as a Sustainable Millennium Development Goal in 2015, leading to increased research and policymaker interest in reducing losses to insure food security. This article analyzes the factors associated with self-reported harvest loss among soybean farmers in Paraná, Brazil, using a survey of 243 farmers. The principal–agent problem is the most important contributor to harvest and postharvest losses on the farm. Loss is lowered when the combines are operated at slower speeds and are adjusted properly, but combine operators have incentives to complete harvesting jobs and deliver soybean to storage facilities quickly. Farmers report training of the combine operators as one of the most important causes of postharvest loss. Empirical results show that farmers report a 1.5 percentage points higher harvest loss when they ask a third party to harvest. Similarly, the farmers' education level is negatively associated with harvest loss; farmers with college completion have 1.6 percentage points less loss compared to farmers with less than fourth grade. However, larger planted areas are associated with higher harvest loss. The paper suggests that who harvests the crop is critical in reducing harvest loss. Policies and contract designs that align incentives between farmers and combine operators might reduce harvest and postharvest loss.

1. Introduction

Within the last decade, donors and researchers have focused attention on food waste and harvest and postharvest loss. Threats to food security due to climate change led policymakers and researchers to measure and reduce food losses. Rosegrant et al. (2018) attributed the resurging interest in reducing food losses to spikes in food prices in 2008 and 2011. In 2015, the United Nations included halving food waste by 2030 as Sustainable Development Goal 12: Responsible Consumption and Production (United Nations, 2021). Reducing food losses implies less expansion of agricultural production onto uncultivated land, therefore reducing greenhouse gas emissions. It also implies less waste of water, fuel, and fertilizer (Shafiee-Jood and Cai, 2016; Galford et al., 2020). At first glance, cutting food losses seems straightforward, but these actions involve costs. Also, they involve changes in behavior among producers, harvesters, transporters, and storage managers. Incentives must be aligned with minimizing food loss throughout the supply chain. The costs of making these changes might not exceed the benefits of the reduced losses.

Research efforts focus on measuring harvest and postharvest losses. Obtaining high-quality data remains a challenge. In 2011, the Food and Agriculture Organization of the United Nations released a study that estimated that one-third of the physical mass of food is lost or wasted globally (FAO, 2011). This statistic attracted attention from policymakers, but as Sheahan and Barrett (2017) argued, it was based on poor quality data and untested assumptions. The African Postharvest Losses Information System (APHLIS) was set up in 2009 to obtain better data and expanded into APHLIS+ in 2015 with primary support from the Bill and Melinda Gates Foundation. The World Bank devoted resources to studying harvest and postharvest loss through new data collection efforts through the Living Standards Measurement Surveys in Malawi, Tanzania, and Uganda (Kaminski and Christiaensen, 2014). Efforts to measure harvest and postharvest loss have lagged in Latin

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America (Fabi et al., 2021), although researchers at IFPRI included two supply chains in four Latin American countries in a recent project (Delgado et al., 2021b). Research on harvest and postharvest loss in Brazil focuses on specific stages in the supply chain, such as losses due to combines during soybean harvest.

We focus on harvest loss for soybean farmers because of its importance to global trade and focus on Brazil because of its importance as a global producer. Soybeans and their derivatives account for over ten percent of global agricultural trade by volume, and they are the most traded agricultural commodity (Lee et al., 2016). Brazil occupies an important and unique position in reducing harvest and postharvest loss of soybean. In 2019, Brazil was the top global soybean producer, with the United States its only close competition (FAO, 2019). Soybean is Brazil's most important export, accounting for US$33 billion in 2017 (World Bank, 2020). Therefore, given the volume of soy produced, decreases in losses have a large impact.

This article contributes to the literature on harvest and postharvest loss by analyzing self-reported losses by soybean farmers in Western Paraná State, Brazil. We first summarize previous literature about Brazil, including journal articles, theses, and government reports that have only been available in Portuguese. Using a representative sample of soybean farmers in the region, we examine associations between reported harvest and postharvest losses and farmer and farm characteristics. Our findings have important implications for reducing harvest loss through incentives and policies.

The rest of the article is organized as follows. Section 2 presents previous studies on harvest and postharvest loss, then focuses on studies in Brazil. Section 3 presents the data and descriptive statistics. In particular, we focus on the relationship of farmers' characteristics to their decisions to harvest their own crops or hire others to harvest. Section 4 presents our empirical methodology and results. Section 5 discusses the estimation results and policy implications, and Section 6 concludes.

2. Literature review of harvest and postharvest loss

Recent studies have refined the global estimates of harvest and postharvest loss. After estimating food loss and waste as being equal to one-third of production (FAO, 2011), the Food and Agriculture Organization (FAO) presented revised estimates of 14 percent for food loss (defined as losses between the farm and the retail level) (FAO, 2019) and 17 percent for food waste (defined as losses from households, food service, and retail) (United Nations Environment Programme, 2021). The total of 31 percent is close to the earlier estimate of one-third. Using machine learning to do a meta-analysis of food loss, Fabi et al. (2021) estimated food losses of 3.8 percent for the group "other crops," which included pulses and oilseeds like soybean. However, the data set compiled by Fabi et al. (2021) did not include any studies of soybean in Brazil.

In the literature, harvest and postharvest losses are categorized into three components: (1) harvest loss, (2) short-haul loss, and (3) storage loss (Goldsmith et al., 2015).[1] This paper focuses on the first stage, harvest loss, which is defined as the difference between the grain yield in the field and the quantity harvested. Two approaches are used to measure harvest and postharvest losses. The first is a systems approach, in which researchers model grains as they pass from the farm and are transported, stored, and sold along the supply chain to the retailer. The second is to focus on measuring losses at points along the supply chain by asking participants about their perceived losses. For example, the IFPRI studies conducted surveys of producers, middlemen, and processors (Delgado et al., 2021b). Our approach is similar to the IFPRI approach, focusing on producers and losses that occur during harvest. Our focus is consistent with previous research on Brazil, which indicates that more losses occur during harvest than during short-haul transportation, storage, or long-haul transportation (Caixeta-Filho and Péra, 2018; Barbosa et al., 2020).

Past systematic studies highlighted the importance of farmers' decisions and the socioeconomic context in which farmers operate. Delgado et al. (2021b) presented the results from a series of studies by the Consortium of International Agricultural Research Centers (CGIAR). They conducted surveys of producers, middlemen, and processors, focusing on the supply chains of potato in Peru and Ecuador, maize and beans in Honduras and Guatemala, teff in Ethiopia, and wheat in China. The interviewees gave their estimates of their losses. Losses amounted to between 6 and 25 percent of total production. Losses at the producer level, including preharvest, harvest, and postharvest losses, accounted for 60 to 80 percent of the total value chain losses. The main causes of harvest and postharvest losses, with the exception of wheat in China and teff in Ethiopia, were damages to crops caused by workers during harvesting or storing due to lack of training. Delgado et al. (2021b) concluded that understanding the demographics of farmers, including education, gender, and experience, is key to understanding loss. Delgado et al. (2021a) developed this point further, showing that the effects of the farmer's gender on food loss differed across contexts. Producer education and experience were associated with a decrease in food loss, but not in all contexts. These findings justify our focus in this paper on farmers' decisions, which is where most of the harvest and postharvest loss occurs.

Our study uses a similar methodology to systematic studies conducted by the World Bank. These studies used farmers' self-reports of farm-level harvest and postharvest losses that were collected through questions asked in the Living Standards Measurement Surveys in Malawi, Tanzania, and Uganda. They found that farm-level postharvest loss was equal to about 1.4 to 5.9 percent of farm production. This was much lower than the FAO's estimate of eight percent losses (Kaminski and Christiaensen, 2014).

Brazil and the United States are both leading countries in soybean production. However, Brazilian producers face unique problems relative to producers in the United States. The Brazilian soybean supply chain is characterized by a shortage of both on-farm and off-farm storage and by a reliance on transport by trucks over roads to reach ports. Farmers need to move their grain immediately to off-farm storage facilities, grain dealers, or ports. Often, the farmers hire combine operators and truck drivers to harvest soybean, and these contractors have incentives to minimize harvest time and transportation time (Caixeta-Filho and Péra, 2018). Producers also have incentives to harvest quickly (Goldsmith et al., 2015) because the soybean harvest is followed immediately by corn planting for the safrinha, or "small harvest." These incentives work against the minimization of harvest losses.

The setting of our study, Paraná, is an area that contributes a significant share of Brazil's soybean production. Located in the south of Brazil, Paraná state accounted for about 15 percent of Brazil's soybean production, ranking third among Brazilian states (IBGE, 2020). In 2018, the region of Western Paraná state produced 3.1 percent of Brazil's total soybean production (IBGE, 2021). In 2010, storage capacity was sufficient to store 92 percent of the total production of corn and beans. In Paraná, storage is not as large of a problem as it is in other top-producing states, such as Mato Grosso (Gonçalves, 2011). Smallholder family farms predominate in the area, providing another contrast with Mato Grosso. In the region where we conduct our study, smallholder family farms account for 76 percent of rural establishments (IBGE, 2017). To the extent that we can measure harvest and postharvest losses and suggest policies and practices to reduce the loss, smallholder farmers will benefit from higher income and will contribute to global food supplies.

Measuring Losses in Brazil A recent review by Barbosa et al. (2020) summarized the literature on loss and waste for soybean in

[1] Long-haul loss refers to transportation from a collection point to a port, which is beyond the farmer's management.

Brazil, concluding that one percent of losses were in the preharvest phase, four percent occurred at harvest, 0.5 percent during short-haul transportation, and 0.25 percent in long-haul transportation. In addition, Caixeta-Filho and Péra (2018) estimated that two percent was lost during storage. Summing these losses, a total of about eight percent of soybean production was lost. The harvest process accounted for the highest proportion of the loss, justifying our focus on it in this study.

The Brazilian literature includes many studies of harvest loss. Results have varied greatly, with some finding high levels of losses and others finding losses within acceptable limits. Losses were estimated to be between 160 and 420 kg per hectare in the 1980s (Conte et al., 2020). The standard set by Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), the federal government's research institute for agriculture, established 60 kg per hectare (one saco per hectare) as the upper bound on acceptable losses during harvest (Silveira and Conte, 2013).[2]

In Paraná state, EMBRAPA SOJA started an initiative in 2018 to measure harvest losses of soybeans. During the 2019/20 harvest, they collected data from 624 farms in five macroregions of Paraná. Researchers measured the grains left in the field within a two-square meter area immediately after the combine passed through, or up to two days afterward. They did three measurements on each farm. Average yields in the state were 3840 kg per hectare. Average harvest losses were 63 kg per hectare in 2019/20, which was lower than the 70 kg per hectare reported in the previous year. In our study area of Western Paraná, losses were above an average for the state, with 83 kg per hectare in 2019/20, up from losses of 67 kg per hectare in 2018/19 (Conte et al., 2020).

Looking at the causes of harvest losses discussed in the Brazilian literature, a dominant theme is the importance of the training of the operator. For optimal performance, the combine must be adjusted properly. Studies have focused on the importance of the adjustment of the cutting platform (Cagol, 2017; Paulsen et al., 2014; Cól et al., 2019), the maintenance of the machine (Zandonadi et al., 2015; Carvalho de Oliveira et al., 2014; Schanoski et al., 2011), and the adjustment of the speed of the reel and the distance settings between parts (Bock et al., 2020; Ferreira et al., 2007; Neto and Troli, 2003).

Another aspect of harvesting that is under the control of the combine operator is the speed at which the combine travels across the field. Research from the early 1980s cited in Martins et al. (2014) found that speeds in excess of seven km per hour caused losses to increase rapidly. Evidence for the effect of combine speed on harvest losses was mixed. Studies in Mato Grosso (Paulsen et al., 2014), Minas Gerais (Carvalho Filho et al., 2005), Rio Grande do Sul (Bock et al., 2020), and Paraná (Dalosto, 2017) found that losses are higher at higher combine speeds,[3] while other studies found no effect in Rondônia (Menezes et al., 2018), Mato Grosso (Carvalho de Oliveira et al., 2014), São Paulo (Ferreira et al., 2007), and Paraná (Schanoski et al., 2011).[4] Chioderoli et al. (2012) found that the speed displacement mattered for the quality of the soybean, but losses were still within acceptable bounds.

Brazilian researchers have examined whether new combines have lower losses than old combines, with mixed results. Combines with draper headers had lower losses than combines outfitted with a screw conveyor in Rondônia (Menezes et al., 2018). Machines using axial mechanisms had lower losses than machines using radial mechanisms, and newer machines had lower losses than older machines in Paraná (Dalosto, 2017) and in Minas Gerais (Campos et al., 2005). Conte et al. (2020) also found a positive association between the age of the combine and losses. However, Maurina (2014) argued that the ability of the operator was more important than the age of the machine to minimize harvest losses.

The principal–agent problem plays a role in losses during harvest. Producers who harvest their own soybean report smaller losses than producers who hire combine operators. Campos et al. (2005) in a study during the 2002/03 harvest found that farmers who harvested with their own combine had losses of 78 kg per hectare whereas those who hired a combine operator had losses of 126 kg per hectare. In Martins et al. (2014), farm managers estimated losses of 10.4 percent during harvest, with harvest losses accounting for 5.7 percent and short-haul transport and storage accounting for the rest. Whether the farmer contracted out for harvesting did not have a significant impact on reported losses. Cól et al. (2019) included a discussion of the principal–agent problem due to the incentives of the combine operator to operate at excess speed. Conte et al. (2020) showed that in Paraná during the 2019/20 soybean harvest, losses were more strongly correlated with whether farmers harvested themselves or hired others than with whether the combine operator had received training or not.

The timing of the harvest is also crucial. The optimal humidity for soybean during harvesting is between 13 and 15 percent (Silveira and Conte, 2013). At low humidity, soybean grains shatter, lowering their quality and the price paid to the farmer. Studies by Paulsen et al. (2014), Cagol (2017), Holtz and Reis (2013), Dalosto (2017) and Neto and Troli (2003) all found that low humidity was a major cause of harvest losses in their trials.

An innovative way to reduce harvest losses and align the incentives of the producer with the incentives of the combine operator is through competitions. The state government extension agency EMATER conducted competitions in which the combine operators with the lowest losses won prizes such as television sets. The average loss measured during the competitions fell from 72 kg per hectare in 1998/99 to 32 kg per hectare in 2013/14. Extension conducted courses for operators in the area. From the competition experience, EMATER concluded that the ability of the operator was more important than the age of the machine to minimize harvest losses because some of the lowest losses were found for operators who were using old machines (Maurina, 2014).

These losses are economically significant. Recent studies in Western Paraná that collected data from actual harvests found losses that were well above the EMBRAPA norm of 60 kg per hectare at 118 kg per hectare (Dalosto, 2017) and 207 kg per hectare (Cól et al., 2019). In our sample, we found the average perceived loss was 103 kg per hectare. Paulsen et al. (2014) estimated that lowering losses by 120 kg per hectare would increase farmers' revenue by US$238 to US$277 per hour of harvest time, which is much higher than the combine operator's hourly wage. Romani et al. (2019) calculated that harvest losses amounted to a value of R$ 111.5 million reais in Western Paraná state. Conte et al. (2020) calculated the value of the losses over the limit of 60 kg per hectare at R$40.7 million reais in Paraná in 2019/20.

3. Data and descriptive statistics

This research aims to investigate self-reported harvest loss and its associated factors using primary data collected by the research team in Western Paraná, Brazil.[5] The sample used in this paper was representative of the population of soybean farmers in Western Paraná. We

[2] According to Conte et al. (2020), the standard of 60 kg per hectare of acceptable losses was based on standards established in the United States using combines manufactured in the 1980s.

[3] In these studies, the speeds of the combines that were considered were as follows: Paulsen et al. (2014)—four to 6.5 km/h, Carvalho de Oliveira et al. (2014)—four to eight km/h, Bock et al. (2020)—three to nine km/h, Dalosto (2017)—three to ten km/h, average of three km/h.

[4] In these studies, the speeds of the combines that were considered were as follows: Menezes et al. (2018)—six to eight km/h, Carvalho de Oliveira et al. (2014)—5.5 and seven km/h, Ferreira et al. (2007)—three to six km/h, Schanoski et al. (2011)—two to ten km/h. Schanoski et al. (2011) note an increase in losses after a speed of six km/h.

[5] This research is funded by the ADM Institute for the Study of the Prevention of Postharvest Loss to examine postharvest loss of soybean among smallholders.

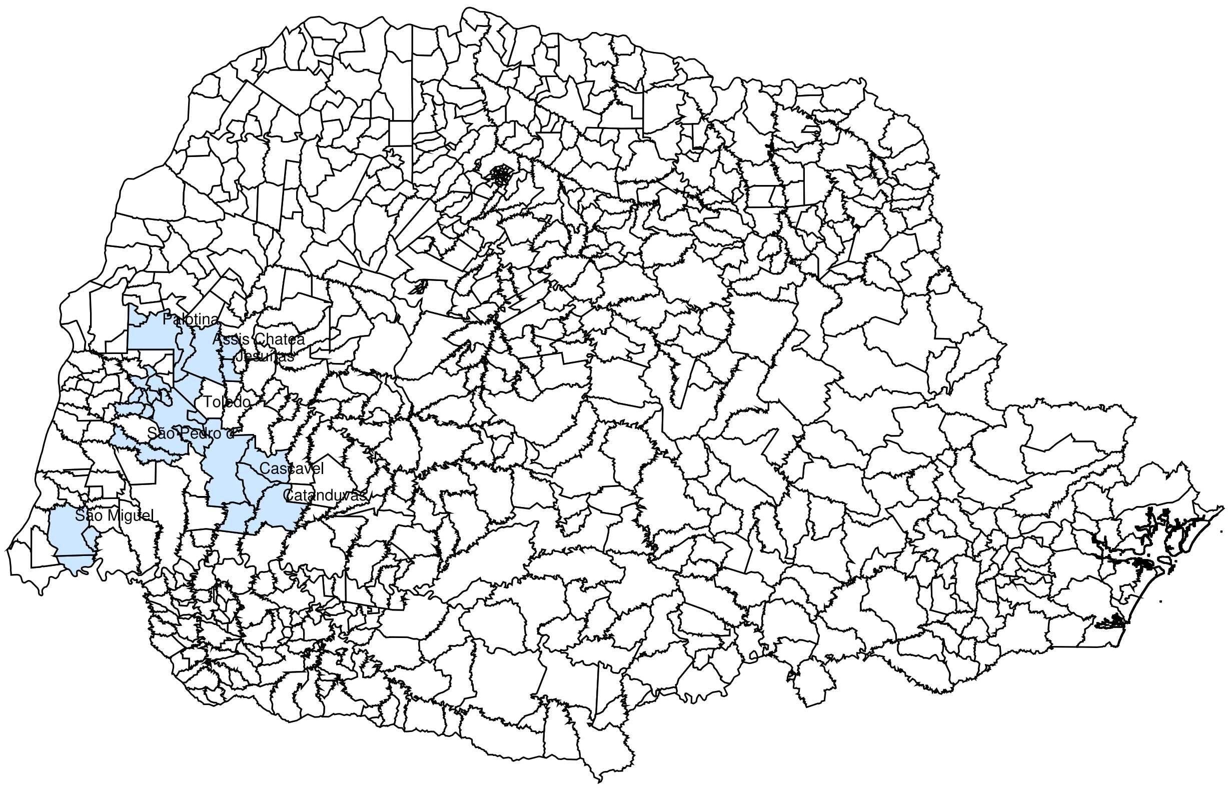


Fig. 1. Sample area, Western Paraná State, Brazil. Notes: The colored areas show eight municipalities where the data were collected: Assis Chateaubirand, Cascavel, Catanduvas, Jesuítas, Palotina, São Miguel do Iguaçú, São Pedro do Iguaçú, Toledo.

chose eight municipalities using sampling with probability proportional to size based on a sampling method described in UNICEF (1995). First, we divided Western Paraná into four quadrants and chose two municipalities in each quadrant. Then, we chose sixty farms randomly from each quadrant, or thirty per municipality based on lists of soybean farmers included in the Cadastro do Produtor Rural (CADPRO) of Paraná state (Romani et al., 2019). The chosen municipalities are shown on a map in Fig. 1.

We collected information between July and December 2017 through face-to-face interviews with 243 farmers at their farms in eight municipalities. Our sample consists of 119 (49 percent) smallholder farms, 88 (36 percent) medium holder farms, and 36 (less than 15 percent) large holder farms. The final sample includes 243 soybean farmers. The survey included information about farmers' general demographic information (age, education, number of children), agricultural activities (harvest, inputs, membership in farmers' groups, participation in government subsidized credit programs such as PRONAF), and on-farm and off-farm labor (Romani et al., 2019).

Fig. 2 shows the farmers' perceptions about which stages involve the highest risk of harvest and postharvest loss. Farmers report the severity using a scale of one to five, where one indicates "not important," and five means "very important." Harvesting is perceived as the most important stage where loss happens, with storage as the second most important stage. Short-haul transportation is perceived as the least important stage because farmers are located close to cooperatives and grain dealers in this area. Farmers perceive the training of the combine operator as the most important factor to explain loss at the time of harvest.

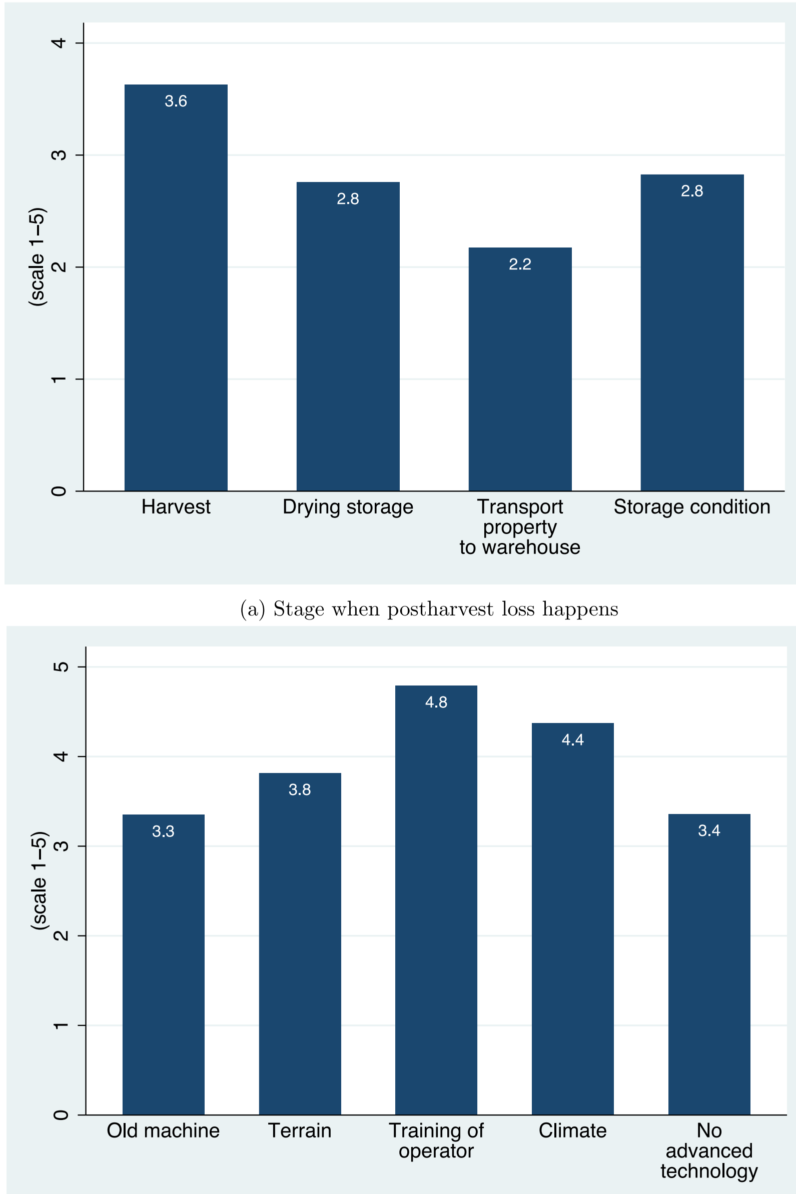
Table 1 shows the individual characteristics of 243 farmers grouped by whether farmers harvested the land by themselves or hired others to do so.[6] The average age of farmers is 49.6 years old. The majority (98 percent) of them are male. There is a wide range of education levels among farmers in our sample, with eight percent of them having less than a fourth-grade education, whereas 23 percent of them have completed a college degree.

Farmers in this area also have a safrinha or planting corn in rotation after the soy is harvested. Ninety-one percent of the farmers in our sample also produce corn. As Goldsmith et al. (2015) showed, this increases the motivation for farmers to harvest quickly and to trade off losses in order to plant the corn crop quickly. In our sample, only four percent grow solely soy.

Approximately 46 percent of farmers (N = 114) harvest their crops by hiring others. Those farmers are relatively older, have less education, and have smaller landholdings compared to those who harvest themselves. Among farmers who hire others to harvest, 77 percent of them are smallholders, whereas only 24 percent of farmers who harvest crops themselves are smallholders. For those who hire others to harvest, 93 percent of them contract with Terceiros (third parties), and only four percent of them contract through Parceria (partnership) (results not shown). Of those who hire others to do the harvesting, four percent of the farmers pay a fixed amount, and 96 percent pay based on a percentage of the crop. Among those who pay a percentage, the average rate is 6.03 percent of the crop harvested.

On average, farmers produce approximately 4000 kg per hectare, which is close to the global standard for soy yield (Njira et al., 2013; Corley, 2019). The yield level of farmers does not differ by whether they harvest themselves or not. However, the perceived amount of harvest loss is larger for farmers who contract with other parties to harvest (120 kg per hectare, or 3.0 percent) compared to farmers who

[6] The variable of "Harvest own" is defined as one if farmers answered yes to the following question: "Você mesmo colhe o grão?" (Do you harvest the grain yourself?). The wording is unambiguous in Portuguese, implying that the farmers themselves drive the combine for harvesting if they answered yes.



(a) Stage when postharvest loss happens

(b) Causes of harvest loss

Fig. 2. Harvest loss and its reported causes (scale 1–5).

harvest by themselves (88 kg per hectare or 2.2 percent).[7] Fig. 3 shows the density distribution of harvest loss by whether farmers harvested the land by themselves or asked others to do so. The distribution of harvest loss has a longer tail on the right for farmers who hire others to harvest, indicating larger harvest losses for these farmers than for those who harvest themselves.

Before the actual data collection of the data used in the main analysis, we also conducted a small pilot study of 58 farmers in which we measured harvest losses using the EMBRAPA method. We used a convenience sample of farmers affiliated with the Lar Cooperative and who were located west of the municipalities chosen for our main sample. The average losses were 74 kilograms per hectare, which was close to the losses that Conte et al. (2020) reported for the region in 2018/19 (67 kg per hectare) and 2019/20 (83 kg per hectare). About half of the sample had losses that were above the 60 kg per hectare limit set by EMBRAPA. We note that the perceived losses of 103 kilograms per hectare in our random sample, the main sample that we use for analysis, were higher than the average measured losses of 74 kg per hectare for our convenience sample. But given the small size of our convenience sample, its non-representativeness, and its lack of geographical overlap with our main sample, we avoid making further statistical inferences from the convenience sample.

[7] Farmers in the study areas are aware of the concept of postharvest loss, thanks to multiple agriculture extension programs. EMBRAPA's low tech method to measure harvest loss has been widely disseminated, and extension agents and Cooperative agents encourage harvest loss measurement. In the survey, we asked, "Did you notice grain loss during harvest when the combine crossed the field? How much do you estimate you lost? In bags per alqueire (local unit for the measurement of land)". The survey question in Portuguese is "Você percebeu perda de grãos durante a colheita quando a colheitadeira atravessou o campo? Quanto você estima que perdeu? Em sacas por alqueire."

Table 1
Farmers' characteristics by harvest mode in Western Paraná, 2017.

	Full sample	Harvest by others	Harvest own	Min	Max
Panel A: Demographic characteristics					
Age	49.64	52.33	47.26	21	82
Male	0.98	1	0.96	0	1
Education level					
Less than fourth grade	0.08	0.13	0.04	0	1
Completed fourth grade	0.23	0.28	0.19	0	1
Completed eighth grade	0.14	0.14	0.13	0	1
Completed high school	0.33	0.32	0.33	0	1
Completed college	0.23	0.13	0.31	0	1
Panel B: Farm characteristics					
Percent of total income that is ag income	93.97	94.39	93.60	5	100
Total landholding (hectares)	161.78	58.86	252.73	3.63	1936
1–72 ha (small)	0.49	0.77	0.24	0	1
72.1–270 ha (medium)	0.36	0.19	0.51	0	1
270.1–1936 ha (large)	0.15	0.04	0.25	0	1
Total planted areas (hectares)	133.41	46.76	209.98	2.90	1599.62
Harvest own	0.53	0	1	0	1
Hired the same person in other crops	.	0.87	.	0	1
Payment to harvester paid as fixed rate	.	0.04	.	0	1
Payment to harvester paid as percent	.	0.96	.	0	1
Percent payment to harvester	.	6.03	.	3	8
Other crops					
None	0.04	0.08	0.01	0	1
Wheat	0.30	0.23	0.36	0	1
Corn	0.91	0.88	0.93	0	1
Panel C: Harvest and loss					
Amount produced (kg/ha)	4035.21	3999.13	4067.10	2603	5876
Harvest loss (kg/ha)	103.16	120.17	88.12	0	496
Harvest loss (percent of total production)	0.03	0.03	0.02	0	0.16
Moisture					
7.5–12.5 percent	0.11	0.14	0.08	0	1
13–15 percent	0.67	0.64	0.71	0	1
15.5–24 percent	0.22	0.22	0.22	0	1
Panel E: Machine characteristics					
Machine type					
John Deere	0.36	0.37	0.35	0	1
New Holland	0.54	0.59	0.50	0	1
Massey Fergurson	0.06	0.03	0.09	0	1
Case	0.03	0.01	0.05	0	1
Machine age					
1960/1999	0.08	0.03	0.12	0	1
2000/2009	0.26	0.25	0.26	0	1
2010/2013	0.24	0.27	0.22	0	1
2014/2018	0.36	0.33	0.39	0	1
Observations	243	114	129	243	243

Notes: Observations are at the farmer level.

4. Empirical strategy and results

To investigate the relationship between harvest loss and farmers' characteristics, we estimate the following equation:

$$y_i = \alpha + \beta_1 HarvestOwn_i + X_i + \theta_{municipality} + \epsilon_i \quad (1)$$

where y_i is the harvest loss reported by farmer "i" as a percentage of the total production. The coefficient for $HarvestOwn$ is the parameter of interest. To control for other factors related to cultivation, we control for farmers' characteristics such as education level and age, landholdings, as well as machine characteristics such as machine brand and year of purchase. The estimation includes fixed effects for the eight municipalities to control for any unobserved characteristics that vary across areas and that affect harvest loss. Standard errors are clustered at the municipality level.

Table 2 shows the estimation results.[8] Column 1 shows the estimation result with only the "harvest own" variable, excluding other controls. Farmers who harvest by themselves have almost one-percentage-point-lower reported harvest loss. The magnitude of the estimated coefficient increases as we include controls and becomes 1.5 percentage points in our preferred specification that includes municipality fixed effects (Column 4). In Column 5, we add two variables to control for the payment modality, including controls for the percentage of the harvest paid to the hired combine operator and the percentage squared. Neither variable is statistically significant, and the "harvest own" variable becomes statistically insignificant. Note that the omitted category for the estimation in columns 1–4 consists of farmers who hired others to harvest. The omitted category for the estimation in column 5 consists of farmers who hired others to harvest and paid a fixed rate (N = 5).

The farmers' education level shows a clear association with harvest loss. Farmers who completed college degrees have a 1.6 percentage

[8] Appendix B shows the estimation results with full set of explanatory of variables.

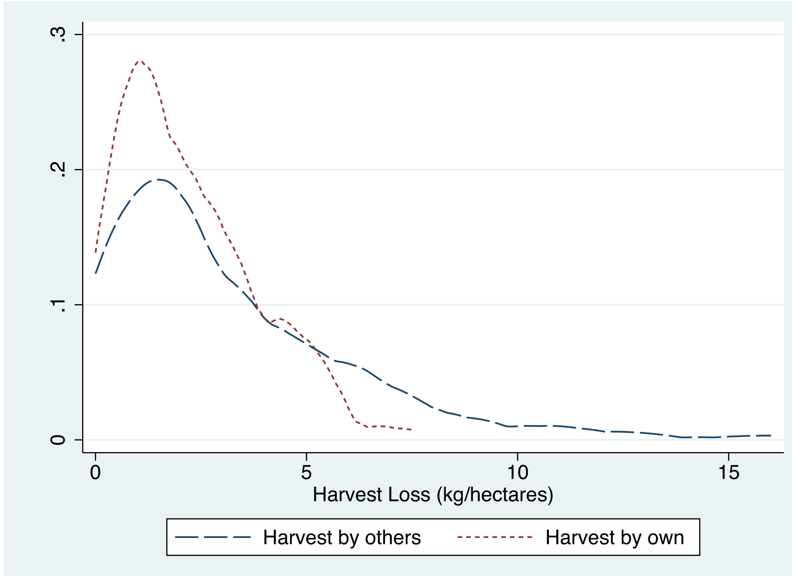


Fig. 3. Density of harvest loss (percent).

points lower amount of harvest loss compared to farmers with less than a fourth-grade education level. Although they are not statistically significant, the other education-level coefficients show a clear gradient, with less loss as education increases.

The moisture level also shows a clear relationship with harvest loss. Compared to the optimal moisture level of 13–15 percent, a lower moisture level of 7.5–12.6 percent is associated with a 1.1 percentage points higher loss. A higher moisture level of more than 15 percent is associated with 0.8 percentage points higher loss (t = 1.71), which is not statistically significant at conventional levels.

In terms of landholding, large farm areas are associated with higher harvest loss. Compared to small farmers, farmers with more than 270 ha of the land report 1.8 percentage points higher loss. We interacted the variables harvest own and land size, but did not observe any statistically significant relationship, indicating that the postharvest loss is less when farmers harvest themselves regardless of farm size (results upon request).

Columns 4 and 5 include controls for the brand of the combine and its year of production. None of the machine characteristics make a difference in the reported percent of harvest loss. However, given that farmers and operators continue to use old combines if they operate well and replace them when broken, it is unclear whether this machine information captures the unbiased relationship with harvest loss. The decision to use a new model machine is endogenous, as it is correlated with both losses and unobserved characteristics.

5. Discussion

Our main finding is that the principal–agent model best explains harvest and postharvest losses among soybean farmers in Western Paraná state. Farmers in our analysis, on average, lose three percent (103 kg) of the amount produced. The estimations suggest that farmers report a 1.5 percentage points higher harvest loss when they ask a third party to harvest (compared to harvesting by themselves). This was more important than the type of combine used or the age of the combine. These findings are in agreement with those of Campos et al. (2005) in Minas Gerais, and Conte et al. (2020) in Paraná. Consistent with the discussion from Cól et al. (2019), the principal–agent problem due to the incentives of the combine operator could be a contributing factor for the harvest loss. Additionally, during harvest time, combine operators face high demand for their services. This push to finish harvesting for multiple farmers during the optimal harvesting season may explain why combine operators operate at excess speed.

Because we are analyzing farmers' perceived losses instead of actually measured losses, we might be concerned that farmers are better able to estimate losses when they drive the combine themselves than when they have hired others to drive the combine. This could be due to both measurement error, because the farmer is more likely to do the measurements when he is in the field harvesting, and due to bias, such as when a farmer believes he is better at harvesting than a hired worker. Using a subsample of 32 farms in the convenience sample, we find that farmers are, if anything, underestimating the losses when they hire others. We compared the difference between measured losses and perceived losses for the farmers who harvested their own soybeans and those who hired others to harvest. Although farmers who "harvest own" have self-reported error compared to the measured loss, the average of this self-reported error was zero, indicating no bias from self-reporting. For farmers who ask others to harvest, they, on average, estimated losses of 1.44 kg per hectare less than the measured loss. Therefore, farmers who hire others to harvest believe that the third party is making a smaller amount of postharvest loss than they actually do. Estimated results of "harvest by others" are more likely to underestimate the actual loss. Details about this analysis are available in Appendix A.

Losses are higher when the moisture levels of the grain are below 13 percent. This is consistent with findings by Paulsen et al. (2014), Cagol (2017), Holtz and Reis (2013), Dalosto (2017), and Neto and Troli (2003). Farmer education also mattered, with farmers who completed college reporting lower losses. This is consistent with the arguments presented in Delgado et al. (2021b,a) that the characteristics of farmers affect losses.

Table 2
Harvest loss (percentage), Western Paraná State, Brazil, 2017.

	(1)	(2)	(3)	(4)	(5)
Harvest own	−0.009*	−0.013**	−0.014**	−0.015***	−0.007
	(0.004)	(0.005)	(0.004)	(0.004)	(0.011)
Education level (Base: Less than fourth grade)					
Completed fourth grade		−0.000	−0.001	−0.002	−0.002
		(0.007)	(0.006)	(0.005)	(0.006)
Completed eighth grade		−0.001	−0.003	−0.003	−0.003
		(0.007)	(0.006)	(0.005)	(0.005)
Completed high school		−0.002	−0.003	−0.006	−0.006
		(0.005)	(0.005)	(0.006)	(0.006)
Completed college		−0.011	−0.014*	−0.016*	−0.017*
		(0.006)	(0.007)	(0.008)	(0.008)
Moisture (Base: 13–15 percent)					
7.5–12.5 percent		0.012**	0.011*	0.011*	0.012*
		(0.005)	(0.005)	(0.005)	(0.006)
15.5–24 percent		0.011	0.009	0.008	0.008
		(0.006)	(0.006)	(0.005)	(0.005)
Landholding (Base: 1–72 ha)					
72.1–270 ha (medium)		0.007*	0.007*	0.006	0.006
		(0.003)	(0.003)	(0.004)	(0.003)
270.1–1936 ha (large)		0.016***	0.018***	0.018**	0.019**
		(0.004)	(0.005)	(0.007)	(0.007)
Machine year (Base: 1960–1999)					
2000/2009				0.001	0.001
				(0.006)	(0.005)
2010/2013				−0.001	−0.001
				(0.004)	(0.004)
2014/2018				0.000	0.001
				(0.006)	(0.006)
Missing				−0.011**	−0.011**
				(0.004)	(0.004)
Other crops (Base: no other crop)					
Wheat				0.005	0.005
				(0.004)	(0.004)
Corn				−0.003	−0.003
				(0.012)	(0.012)
Percent payment to harvester					0.001
					(0.007)
Percent payment to harvester (square)					0.000
					(0.001)
Age control	No	Yes	Yes	Yes	Yes
Municipality FEs (8)	No	No	Yes	Yes	Yes
Machine type control	No	No	No	Yes	Yes
Mean	0.03	0.03	0.03	0.03	0.03
Adjusted R^2	0.03	0.07	0.13	0.12	0.12
Number of observations	243	243	243	243	243

Notes: Notes: Observations at farmer level. The dependent variable is harvest loss, measured as a percent of the total production. Age control is the dummy variable of farmers' age in 10 years increment. Municipality FEs include fixed effects for eight different municipalities, and machine type control includes the control variables of combine makers such as John Deere or New Holland. Standard errors clustered by municipalities are in parentheses.

*$p < .10$.

**$p < .05$.

***$p < .01$.

Policy Implications

Farmers might be encouraged to own and operate their own equipment, eliminating the principal–agent problem. The estimated coefficient of the paper shows that the variable harvest own is associated with a reduction of harvest loss by 0.015. If the harvest loss is reduced by 1.5 percent of production, the absolute amount of farmers' harvest loss will be 60 kg/ha.[9] Because the average planting land size of the farmers for "harvest by others" is 46.8 ha, the harvest loss associated with asking others to harvest their entire field is 2808 kg for the average farmer in each harvest season, which is equivalent to US$ 1797 (with the rate of US$ 0.64 per kg). Therefore, farmers could save US$ 1797 of harvest loss each harvest season by avoiding the harvest loss incurred by hiring others. Thus, a program to reduce the postharvest loss from monitoring or creating payment/award schemes for contracting would be beneficial if the program costs less than US$ 1797.

If the policy is to encourage farmers to harvest their own land, another item for cost reduction is the payment to others. The majority of the farmers (96 percent) pay the harvesting portion to contractors who harvest their soy. The average rate of the payment is six percent of the harvest (Table 1 in the paper). Because the average total planted areas of farmers who ask others to harvest is 46.8 ha, and the total production of soy per hectare is 3999, the total soy production in each harvest season is 187,153 kg. Six percent of 187,153 kg is 11,229 kg. That means the payment for the third party is equivalent

[9] The average soy production from the "harvest by others" farmers is 3999 kg/ha (Table 1).

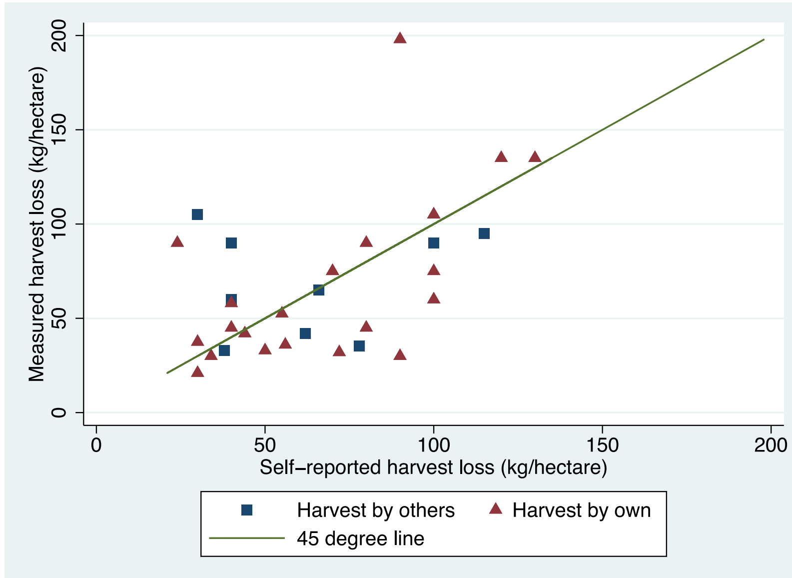


Fig. A.1. The scatter plot of measured and self-reported postharvest loss (kg/ha).

to US$ 7286. Considering those two components, farmers can save up to US$ 9083 (=1797 + 7286) in each harvest season by harvesting the crop by themselves.[10] For the policy implication, we conclude that the program's cost will be cost-effective if the cost of financing the program is less than US$ 9083, which is the estimated benefit from harvesting themselves. This result might inform Brazilian agriculture policy, noting that other researchers have highlighted that the Brazilian government has provided insufficient financial support for agriculture machinery and equipment for small farmers (Aquino et al., 2017; Albiero et al., 2015; Reichert et al., 2015).

Brazil has policies targeted at smallholders to provide them with subsidized credit, such as PRONAF. This credit can be used to purchase equipment such as combines and on-farm storage facilities. We were not able to find any relationship between participation in PRONAF and harvest losses or combine ownership, which might be due to the small size of our sample. In the case where land size is too small to make the purchase of a combine economically feasible, farmers' groups can facilitate the purchase of a combine among neighboring smallholders. In Paraná, farmers are starting to invest in combines. Conte et al. (2020) noted that the percentage of farmers in their sample who owned a combine increased from 58.1 in 2018/19 to 68.4 in 2019/20. The increase in ownership was attributed to high farm incomes due to good harvests and good prices for soybean. However, the government or farmers' groups could also enact policies to facilitate this trend.

Raising awareness of harvest and postharvest losses and enabling farmers to measure them easily are effective, low-tech ways to reduce losses. Conte et al. (2020) discussed how the dissemination of the low-tech EMBRAPA method of measuring losses, which involves a plastic cup, sticks, and string, helped to lower harvest losses. EMBRAPA partnered with local extension agents and training providers to raise awareness of the cost of combine losses. Investment in innovative extension programs can increase the income of smallholders such as the soybean farmers in Paraná (Belik, 2015).

However, researchers and policymakers might want to be cautious about emphasizing the reduction of harvest and postharvest losses when considering policies to improve farmers' standard of living. Other policies might be more cost-effective. Focusing on the African context, Sheahan and Barrett (2017) concluded that other policies are more effective in reducing poverty than policies that aim to reduce harvest loss. Investments might be more effective in improving seed quality, increasing fertilizer use, developing rural financial markets, and improving infrastructure. Rosegrant et al. (2018) noted that better data are needed and that estimates of harvest and postharvest losses vary greatly across settings. Reducing harvest and postharvest loss might be expensive relative to other food security solutions. Technologies developed to reduce harvest and postharvest loss might only be worthwhile for large-scale farms. They concluded that investments in agricultural research and development would be more cost-effective than investments in reducing harvest and postharvest loss. In Brazil, in contrast to Africa, yields are already high, and Brazil is internationally competitive. There might be more scope to have an impact through the reduction in harvest and postharvest losses. Policies to align incentives between producers and combine operators might be effective.

The principal–agent situation in Western Paraná state presents a cautionary tale for policymakers who are considering encouraging farmers to hire others to conduct harvest and postharvest tasks as a solution to losses. Farmers and policymakers should carefully consider the incentives for farmers, combine operators, truck drivers, and other operators along the supply chain.

6. Conclusion and future research

This article analyzes the factors associated with self-reported harvest and postharvest loss among soybean farmers in Western Paraná, Brazil. Farmers in our analysis reported training of the combine operators as one of the most important causes of harvest loss. The empirical results suggest that the principal–agent problem is the major contributor to losses on the farm. The results also suggest that the farmers' education level is negatively associated with harvest loss, but the larger planted areas are associated with higher harvest loss as well.

We note three limitations of our current research and identify areas for future research. First, our measure of harvest loss is self-reported, which may reflect biases in which a farmer views himself as more or less competent as a harvester than a hired worker is. For future research, researchers might collect objective data on harvest losses and ask about farmers' perceived losses before farmers know about actual losses. Actual loss data could be compared with farmers' perceived loss.

[10] Given that the cost assessment of this type of program involves many assumptions, including the program implementer's effort and local context to minimize the cost, we only present the program's benefit as a threshold to make this type of program cost efficient.

Table A.1
Descriptive statistics of the measurement error and bias.

	N	Self-reported postharvest loss (kg per hectare)	Measured postharvest loss (kg per hectare)	Correlation	Measurement error	Bias (Self-reported minus measured) Harvest own
Harvest own	23	69.8	69.8	0.61	21.2	0 kg per hectare
Harvest by others	9	63.2	68.4	0.16	48.3	−5.15 kg per hectare
Total	32	67.9	69.4	0.52	26.6	−1.44 kg per hectare

Second, our results might be subject to bias due to the endogeneity of the decision whether to harvest oneself or hire another worker to do so. To investigate the principal–agent issue further, a detailed analysis of how harvesters behave differently when they are harvesting their own land compared to others' land would reveal this complicated relationship. If the harvester has a small incentive to reduce harvest loss, he or she would be more likely to harvest at a faster speed.

Third, further studies about losses due to short-haul transportation, storage, and climate effects are needed. Preliminary analysis of our data indicated that farmers might have more confidence in their cooperatives compared to other storage sources, but our sample was too small for the estimates to obtain statistical significance. Similarly, longitudinal data collection paired with weather information will reveal the effect of variation in weather on harvest and postharvest loss.

Our analyses have policy implications. There are several possible mechanisms to solve the incentive issue among farmers and harvesters. The first one is to provide resources for farmers to be able to harvest their own land by themselves. In this context, further analysis of the role of agricultural credit and the decision to buy a combine will be valuable for future research. However, the simple provision of combines may not reduce harvest loss. If the lack of knowledge and skills about how to minimize harvest losses or misaligned incentives were the primary reasons for high harvest loss, then training for farmers will play a critical role in reducing harvest loss. Also, owning a combine might not be a good investment for a smallholder, and the averted harvest losses might not be large enough to offset the cost. Better monitoring of the combine operators might also provide a solution to the principal–agent problem. For example, competitions provide incentives for combine operators to adjust machines properly to reduce losses. Another mechanism to solve the agent issue is a better monitoring system when others harvest. Contracts might include random measurements of harvest losses, and pay might be tied to losses.

CRediT authorship contribution statement

Mary Arends-Kuenning: Conceptualization, Methodology, Formal analysis, Funding acquisition, Investigation, Supervision, Validation, Writing – original draft, Writing – review & editing. **Marcos Garcias:** Conceptualization, Methodology, Funding acquisition, Interviewing, Investigation, Writing – original draft. **Akito Kamei:** Conceptualization, Methodology, Formal analysis, Investigation, Project administration, Visualization, Data curation, Writing – review & editing. **Pery Francisco Assis Shikida:** Conceptualization, Methodology, Funding acquisition, Supervision of Interviewing, Resources. **Gisele Esser Romani:** Conceptualization, Methodology, Interviewing, Data entry and cleaning.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Self-reporting and measurement error

Do farmers have accurate perceptions about their harvest losses? We might be concerned that our results are affected by farmer error in estimating their losses and that these errors might be systematically higher when farmers hire others to harvest their crops than when they harvest themselves. To summarize, we want to rule out that our results are driven solely by measurement error. Farmers who ask others to harvest do commonly go to the field to check if there were any losses as a part of their evaluation of how the service was provided. This is a simple, low-tech procedure that involves a calibrated cup produced by EMBRAPA, two wooden sticks, and some string. However, there are two factors that relate to farmer error.

One is the measurement error. If farmers do not harvest by themselves, they may have more uncertainty about the amount of postharvest loss. The other is the farmers' bias directed against hired workers. For example, if farmers ask others to harvest, they may be inclined to report a larger amount of harvest loss. Or on the contrary, farmers who ask others to harvest might report a lower harvest loss compared to reality, believing that a third-party contractor provides a good quality service.

At the beginning of this research project, our researchers conducted a scoping activity to understand the difference between self-reported harvest loss and actual measured harvest loss in the neighboring municipalities in the same region. Because the sample size is small, we provide descriptive results without making any statistical inference from this data. We refer to this data set as a convenience sample.

In the convenience sample, enumerators visited the soybean field within a day after harvest. They measured the postharvest loss several times using a standardized measuring cup provided by EMBRAPA.

The number of observations in the convenience sample is 32 farmers. Among those 32 farmers, 23 harvested their crop by themselves, and the other nine farmers outsourced their harvest to others (see Table A.1). Fig. A.1 provides the scatter plot of the self-reported and measured postharvest loss. The correlation between self-reported and measured loss is 0.52. This correlation is higher for the farmers who harvested themselves (0.61), compared to the ones who did not (0.16). This result highlights that the measurement error is bigger for farmers who ask others to harvest their fields.

In terms of the bias, the measured postharvest loss was 1.44 kg per hectare larger than the self-reported postharvest loss on average. This difference is canceled out for farmers who harvest their own and becomes 0. For the farmers who ask others to harvest, the measured postharvest loss was, on average, 5.14 kg per hectare larger than the self-reported loss. In other words, farmers who asked others to harvest reported a lower amount of self-reported postharvest loss compared to measured postharvest loss, suggesting that farmers overestimated the quality of third-party harvesters and underestimated the amount of loss. Although we avoid making statistical conclusions from the small convenience sample, the data from the convenience sample indicate that farmers underestimate postharvest loss when they ask a third party to harvest. We argue that our result in the main paper is a lower bound of the estimate rather than an overestimation.

Appendix B. Estimation results with all the coefficients shown

See Table B.1.

Table B.1
Harvest loss (percentage), Western Paraná State, Brazil, 2017.

	(1)	(2)	(3)	(4)	(5)
Harvest own	−0.009*	−0.013**	−0.014**	−0.015***	−0.007
	(0.004)	(0.005)	(0.004)	(0.004)	(0.011)
Age of farmers (Base: 21–39)					
40–49		0.000	0.001	0.001	0.001
		(0.005)	(0.006)	(0.005)	(0.006)
50–59		−0.001	−0.002	−0.002	−0.002
		(0.007)	(0.008)	(0.009)	(0.009)
60–82		−0.005	−0.007	−0.007	−0.007
		(0.004)	(0.005)	(0.006)	(0.006)
Education level (Base: Less than fourth grade)					
Completed fourth grade		−0.000	−0.001	−0.002	−0.002
		(0.007)	(0.006)	(0.005)	(0.006)
Completed eighth grade		−0.001	−0.003	−0.003	−0.003
		(0.007)	(0.006)	(0.005)	(0.005)
Completed high school		−0.002	−0.003	−0.006	−0.006
		(0.005)	(0.005)	(0.006)	(0.006)
Completed college		−0.011	−0.014*	−0.016*	−0.017*
		(0.006)	(0.007)	(0.008)	(0.008)
Moisture (Base: 13–15 percent)					
7.5–12.5 percent		0.012**	0.011*	0.011*	0.012*
		(0.005)	(0.005)	(0.005)	(0.006)
15.5–24 percent		0.011	0.009	0.008	0.008
		(0.006)	(0.006)	(0.005)	(0.005)
Landholding (Base: 1–72 ha)					
72.1–270 ha (medium)		0.007*	0.007*	0.006	0.006
		(0.003)	(0.003)	(0.004)	(0.003)
270.1–1936 ha (large)		0.016***	0.018***	0.018**	0.019**
		(0.004)	(0.005)	(0.007)	(0.007)
Machine year (Base: 1960–1999)					
2000/2009				0.001	0.001
				(0.006)	(0.005)
2010/2013				−0.001	−0.001
				(0.004)	(0.004)
2014/2018				0.000	0.001
				(0.006)	(0.006)
Missing				−0.011**	−0.011**
				(0.004)	(0.004)
Machine type (Base: John Deere)					
New Holland				0.004	0.004
				(0.003)	(0.003)
Massey Fergurson				−0.002	−0.001
				(0.007)	(0.007)
Case				−0.006	−0.005
				(0.005)	(0.006)
Dont't know				−0.002	−0.004
				(0.005)	(0.008)
Other crops (Base: no other crop)					
Wheat				0.005	0.005
				(0.004)	(0.004)
Corn				−0.003	−0.003
				(0.012)	(0.012)
Percent payment to harvester					0.001
					(0.007)
Percent payment to harvester (square)					0.000
					(0.001)
Municipality FEs (8)	No	No	Yes	Yes	Yes
Mean	0.03	0.03	0.03	0.03	0.03
Adjusted R^2	0.03	0.07	0.13	0.12	0.12
Number of observations	243	243	243	243	243

Notes: Observations at farmer level. The dependent variable is harvest loss measured as percent of the total production. Standard errors clustered by municipalities are in parentheses. The base of control is Age 21–39, Machine 1960–1999, and 13–15 percent for moisture (optimal).

*$p < .10$.

**$p < .05$.

***$p < .01$.

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