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The impact of Peru’s land reform on national agricultural productivity: A synthetic control study

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ABSTRACT

This paper evaluates the impact of Peru’s collectivist land reform in 1970 on national agricultural productivity. While prior research have shown contrasting impacts of land reform across different settings, few have assessed the productivity consequences of collectivist experiments at the aggregate level. Employing a Synthetic Control Method, we construct a scenario of Peru’s productivity trends in the absence of land reform, drawing on data from comparable Latin American countries unaffected by the reform. We estimate the reform’s effect by comparing actual productivity series with the counterfactual scenario. Our findings reveal a substantial negative impact, with agricultural productivity remaining about 20 % below the synthetic control between 1969 and 1985. Robustness analyses support the causal interpretation of these effects, as our findings remain consistent across various optimization methods, falsification tests, and alternative donor pools. Importantly, we confirm that our results are not attributable to broader economic trends affecting Peru during the land reform period, as similar impacts were not observed in unaffected sectors. A decomposition analysis attributes the reform’s impact to decreases in the overall efficiency of farm production. The shift from individual large landowners to farmer collectives, combined with constraints imposed by an extractive macroeconomic environment, likely disrupted the optimal allocation of resources and technological decision-making within cooperatives, ultimately weakening agricultural Total Factor Productivity.

1. Introduction

Influential research on comparative development has established that historical inequality in landownership can undermine economic development, hinder productivity growth, and increase social tension and polarization over time (Binswanger et al., 1995; Deininger and Squire, 1998; Galor et al., 2009). To address these entrenched disparities, many governments across the developing world implemented drastic land reform programs aimed at dismantling the economic power of landed elites and addressing longstanding peasant demands for land.[1] For various economic and political reasons, numerous reforms adopted collectivization, establishing labor-managed agricultural production cooperatives rather than distributing land to individual family farms. Initially embraced by socialist nations, collectivization later shaped Latin American agrarian policies, with over half of countries in the region attempting collectivist land reform during the second half of the twentieth century (Montero, 2022).

Although empirical evidence generally points to a weak economic track record for collectivist land reform in Latin America (Kay, 1982; Deininger, 1995), its broader impact on national agricultural productivity remains largely unexplored. Micro-level studies that compare cooperative performance with small or large private holdings shed light on the effects of collective organization on farm production and efficiency (Carter, 1984; Carter and Kanel, 1985; Carter et al., 1993), yet they fail to capture how these reform experiments affected aggregate productivity in agriculture. This limitation is particularly important because many collectivist reforms were implemented within an extractive policy framework that constrained agricultural performance. As a result, alternative approaches are needed to assess their overall sectoral impact. To address this research gap, the present study adopts a macro-level perspective on Peru’s collectivist land reform in the early 1970s. Using synthetic control methods, we investigate both the

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[1] As reported by Bhattacharya et al. (2019) and Lipton (2009), land reform during the 20th century affected approximately one billion people and one billion hectares in nearly 150 countries.

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magnitude and trajectory of the reform's impact on national agricultural productivity, taking into account its design and features, degree of implementation, and the complementary policies that affected the sector.

Peru stands as a significant case study of collectivization under a non-communist regime. In 1968, a progressive military regime seized power and initiated a comprehensive land reform that expropriated nearly every large-scale private holding in the country and granted cooperative property rights to former workers and peasants. In term of scope, the reform was substantial, redistributing over 10 million hectares of farmland, making it one of Latin America's most extensive land reforms in terms of agricultural land alongside Bolivia, Chile, Cuba, Mexico, and Nicaragua (Albertus, 2015). The agricultural sector was reorganized through the creation of Agricultural Production Cooperatives, implemented within a broader agrarian policy framework that blended state-led planning with extractive measures designed to channel resources into other sectors (Matos Mar and Mejía, 1980, Kay, 1982). Along with social and political reasons, the reform was intended to increase farm productivity and boost industrialization by extracting surpluses from presumed agricultural growth. How did Peru's land reform ultimately affect national agricultural productivity?

This paper uses the Synthetic Control Method (SCM) approach to assess the impact of Peru's land reform on agricultural productivity at the country level (Abadie et al., 2010; Abadie and Gardeazabal, 2003). The SCM allows us to construct a counterfactual scenario of Peru's productivity trends in the absence of land reform by using data from so-called 'donor units', which are counties that are similar to Peru but were not affected by the reform. This method employs a data-driven procedure to systematically choose comparison units that closely resemble the values of agricultural productivity and predictors for Peru before the reform. We then estimate the effect of the reform by comparing the actual (with reform) and counterfactual (without reform) agricultural productivity series for Peru.

Our findings unequivocally reveal a substantial negative impact of Peru's land reform on agricultural factor productivity. Between 1969 and 1985, labor productivity remained approximately 20 % below that of a synthetic counterfactual comprising Latin American countries. Similar adverse effects were observed using alternative measures of productivity, including land productivity and total factor productivity growth.

Further robustness analyses support the causal interpretation of these impacts, as our findings remain consistent across a variety of optimization methods and falsification tests. Importantly, we confirm that our results are not attributable to broader economic trends affecting Peru during the land reform period, as similar impacts were not observed in unaffected sectors. We also provide additional evidence that our results are not driven by significant changes witnessed in the comparison countries, as our findings withstand scrutiny across various alternative donor pools that include countries beyond Latin America or exclude nations that underwent major or partial land reforms.

A supplementary decomposition analysis of labor and land productivity growth indicates that the reform's detrimental impact on productivity was primarily driven by a decline in overall farm efficiency, as reflected in the downward trend of Total Factor Productivity growth. This decline stemmed from losses in technical and allocative efficiency, diseconomies of scope, and disruptions in technology adoption. Insights from micro-level studies and qualitative research highlights the role of both internal and external factors. Internally, severe management inefficiencies and conflicts within collectives undermined coordination, decision-making, and resource allocation. Externally, an extractive macroeconomic environment—marked by distortive policies and inadequate institutional support—further constrained productivity. Together, these factors were likely the major contributors to the reform's disappointing outcomes.

This paper contributes to the broader literature seeking to unravel the economic repercussions of land reforms. Despite a substantial theoretical debate linking land reform to productivity, the empirical work testing this relationship have been limited, primarily due to data constraints and challenges in identifying credible counterfactuals to isolate the effects of reform. Robust empirical applications often rely on exogenous sources of variation in the location, intensity, and timing of reform to study its *local* impacts, as seen in studies conducted in India that exploit state and district variations in land reform rollout (Banerjee et al., 2002; Bardhan and Mookherjee, 2008; Ghatak and Roy, 2007). In contrast, our study takes a macro perspective, employing a synthetic control approach to examine *global* impacts of Peru's collectivist land reform on national agricultural productivity. A key advantage of this approach is its ability to capture sector-wide effects of agrarian reform policies while maintaining methodological rigor.

Our paper also adds to the existing knowledge gap concerning the developmental impacts of numerous land reforms that created agricultural cooperatives. The empirical literature has primarily centered on examining land reform experiences that established individual family farms (i.e., classic land reforms) or induced changes in agricultural tenancy laws (i.e., tenancy reforms). Finding of these studies have been mixed, even among similar institutional designs and prevailing condition.[2] Our study instead explores a less studied yet significant type of reform aimed at establishing collectives forms of production. Montero (2022) stands out as one of the few studies that investigate the causal effects of cooperative property rights on productivity, focusing on the case study of the 1980 land reform in El Salvador. Montero's findings indicate that land reform cooperatives were less productive in cash crops but more productive in staple crops compared to similar-sized *haciendas* unaffected by the reform. However, the study acknowledges that it is not able to provide conclusive evidence concerning the reform's impact on aggregate agricultural productivity. We extend this literature by drawing from another Latin America experience of land reform that established cooperatives, providing evidence on the overall impact of reform on various productivity metrics, including labor and land productivity and Total Factor Productivity growth.

Finally, this paper also aligns with existing literature examining differences in agricultural productivity across countries. Classical studies by Hayami (1969), Hayami and Ruttan (1970), and Kawagoe et al. (1985) identified several sources contributing to the gap in labor productivity between developed and developing countries. Recent studies have furthered this examination, expanding the focus to include broader metrics like Total Factor Productivity (Bravo-Ortega and Lederman, 2004) and considering factors such as climate variability (Lachaud et al., 2017), geography (Adamopoulos and Restuccia, 2022), land inequality (Vollrath, 2007), and self-selection in agriculture (Lagakos and Waugh, 2016). Our paper distinguishes itself from this body of literature by focusing on a specific policy shock, namely land reform, within a unique context, Peru. This major land redistribution program, however, may have been more decisive in shaping productivity patterns in Peru than many of the previously examined factors.

The remainder of the paper is structured as follows. The next section discusses existing theories and empirical studies linking land reform to agricultural productivity. Section 3 provides background on Peru's land reform, while Section 4 outlines the empirical strategy, which employs synthetic control methods. Section 5 describes the variables and data sources, followed by Section 6, which details the donor pool selection criteria. Section 7 presents the results, including the construction of the synthetic control unit, the estimated impact of Peru's land reform on

[2] Productivity gains from classic land and tenancy reforms have been documented in parts of India (Banerjee et al., 2002; Bardhan and Mookherjee, 2008) and several Asian countries such as Japan, Korea, Taiwan, Vietnam, and China (Fan, 1991; Jeon and Kim, 2000; Kay, 2002; Lin, 1991; Lipton, 2009; McMillan et al., 1989; Pingali and Xuan, 1992). In contrast, productivity losses have been observed in the Philippines (Adamopoulos and Restuccia, 2020) and overall in India (Ghatak and Roy, 2007).

agricultural productivity, an assessment of inferential threats, and a decomposition analysis of labor and land productivity growth. Finally, Section 8 concludes the study by discussing the broader implications of our findings.

2. Collectivist land reform and productivity: theory and empirical evidence

Land reform has long been regarded as a critical policy tool for addressing rural inequality and enhancing agricultural performance in developing countries. While many reforms focus on redistributing large estates to small family farms, some governments experimented with collectivist approaches, pooling land and resources into agricultural production cooperatives managed by peasants and rural laborers. Originally adopted by socialist nations, this model reshaped agrarian reform in Latin America between 1960 and 1980, as governments—motivated by equity and efficiency considerations—placed cooperative farming at the core of agrarian reorganization following the redistribution of land from large and mechanized farms.[3]

The theoretical case for collectivization emphasizes potential economies of scale in production and related activities (inputs supply, marketing), improved access to credit markets, and the possibility of sharing risk and investment across a larger group of producers (Carter, 1987; Binswanger et al., 1995). However, incentive and coordination problems often outweigh these benefits. Free-rider behavior can drive productivity into a "low-effort equilibrium" (Jensen and Mekling, 1979), and collective long-term investment decision can become contentious when members, lacking the ability to sell or transfer their shares, prioritize short-term consumption (Bonin, 1985; McGregor, 1977). Moreover, managerial complexity can escalate in large-scale cooperatives—especially when top-down bureaucratic oversight displaces localized knowledge and autonomous decision-making (Deininger, 1995; Putterman, 1985).

Evidence on collectivization often points to a disappointing track record, with many experiments failing to deliver sustained improvements in agricultural performance (Deininger, 1995; Lipton, 2009). In Latin America, collectivist land reforms frequently fell short of expectations, as agricultural growth did not materialize despite significant state subsidies (de Janvry and Saudoulet 1989; Kay, 2002).[4] The widespread shift toward decollectivization further underscores the failure of collectivist farming structures, as most large-scale collective farms were eventually fragmented into individually managed family farms once parcellation became an option for peasants (Carter, 1987).[5] While these trends suggest that collectivist reforms may have hindered agricultural productivity, their overall impact at the national level and long-term trajectory remain largely unexplored. This is due, in part, to the challenge of isolating land reform effects from broader unfavorable macroeconomic conditions and external forces that shaped the region's economies.

Empirical studies on land reform cooperatives have often attribute poor economic performance to institutional weaknesses that failed to resolve collective action challenges, such as internal conflicts, labor shirking, and underinvestment (Binswanger et al., 1995; Deininger, 1995). These challenges were particularly severe in contexts of mandatory participation and high political interference, as successful cooperation is more likely to emerge in environments with strong social ties and internal democracy (Putterman, 1985). For example, bureaucratic oversight, flawed payment structures, and inadequate contracts led to labor shortages following collectivization in Cuba and Nicaragua (MacEwan, 1981; Enriquez, 1992). However, rigorous micro-level studies in Honduras (Carter et al., 1993), Peru (Carter, 1984), and El Salvador (Montero, 2022) suggest that cooperatives were not necessarily less efficient than large *haciendas* or family farms, highlighting high heterogeneity in cooperative performance. Some cooperatives prospered under effective rule enforcement, voluntary participation, and government support (Carter et al., 1993; Barham and Childress, 1992), while strong local leadership and self-determination were key to success stories in the Dominican Republic (Carter and Kanel, 1985) and Honduras (Ruben and van den Berg, 1997). These findings challenge the notion that agricultural collectives are inherently inefficient and instead emphasize the role of institutional and policy factors in shaping the ultimate outcome of collectivist reforms.

Beyond internal incentive problems, some scholars emphasize external problems impacting production incentives and resource utilization in agriculture, especially via extractive macroeconomic policies that often accompanied collectivist experiments (Putterman, 1985; Dorner, 1992). Many reform projects were subordinate to broader economic development strategies designated to foment growth in other sectors that directly or indirectly affected agricultural performance through subsides, taxes, pricing distortions, and state control in output and input markets (Deininger, 1995).[6] As Putterman (1995) notes, such extractive policies could significantly undermined productivity and accelerate decollectivization, as seen in Tanzania and China. Consequently, the outcomes of collectivist land reform were shaped not only by the reorganization of landownership but also by the broader macroeconomic policies that influenced agricultural production and investment.

Taken together, the experience of collectivization underscores the need to account for structural, institutional, and political factors when assessing the productivity impacts of land reform. To address these elements and examine the aggregate effects on national agricultural productivity, we adopt a macro-level approach, focusing on Peru's collectivist reform of the early 1970s. Peru presents a unique case study to examine the long-term productivity consequences of reform, shaped not only by agricultural reorganization but also by the extractive macroeconomic policies that accompanied these efforts. The following section presents background information on Peru's land reform and reviews the existing literature on its impacts.

3. Background on Peru's land reform

Popular pressure on land disparities and power concentration in Peru since the mid-20th century led to a radical collectivist reform once a progressive military leadership seized power in 1968. With the closing statement "Peasants, the landlord will no longer feed from your poverty," General Velasco enacted Decree Law # 17716 in 1969 and initiated a

[3] Examples of partial or fully collectivist land reform in Latin America include Peru, Chile, Nicaragua, El Salvador, Cuba, Mexico, Guatemala, Honduras, the Dominican Republic, and Costa Rica. Collectives were also established in the Soviet Union, China, Vietnam, Israel, Ethiopia, Portugal, Sri Lanka, and Mozambique, among others (de Janvry, 1981; Binswanger et al., 1995).

[4] A similar disappointing track record of collectives and state farms has been observed among socialist nations, where agricultural total factor productivity growth lagged behind that of comparable non-socialist economies (Pryor, 1992, Chapter 8)

[5] This pattern of shifting from collective to individualized farming has been documented across Latin America—including Peru, Mexico, the Dominican Republic, Chile, Panama, Nicaragua, and Honduras—as well as in socialist economies such as many former Soviet states, China, and Vietnam (Lipton, 2009; Petrick, 2021).

[6] Extractive macroeconomic environments, to varying degrees, have been documented in Latin American land reforms (e.g., Peru, Nicaragua, Honduras, and the Dominican Republic) as well as in collectivization experiments in other regions (e.g., Ethiopia, China, and Tanzania) (Carter and Alvarez, 1989; Carter et al., 1993; Deininger, 1995; Putterman, 1985).

Table 1
Selected predictor of agricultural productivity.

Category	Variable	Description
Resource Endowments	Man/Land ratio[a]	Ratio between the headcount of adults whose main economic activity is agriculture and the total agricultural land in hectares of "rainfed cropland equivalents."
Technology	Machinery/ Land ratio[a]	Ratio between the total stock of farm machinery in "40- metric horsepower tractor equivalents (includes tractors, harvester-threshers, milking machines, water pumps)" and total agricultural land in hectares of "rainfed cropland equivalents."
	Fertilizer/ Land ratio[a]	Ratio Metric tons of N, P2O5, and K2O nutrients for fertilizer consumption and total agricultural land in hectares of "rainfed cropland equivalents."
	GDP per capita[b]	Logarithm of real GDP at constant prices, expressed in mil. 2017 US$ per capita.
Human Capital	Human Capital Index[b]	Based on the average years of schooling from Barro and Lee (2010) and Cohen and Leker (2014).
Land Inequality	Land Gini (circa 1960)[c]	Land Gini coefficient of the size distribution of land holdings. Land is exclusively measured in size (acres or hectares); there are no corrections for the quality, location, or type of land.

[a] Source: International agricultural productivity database (USDA ERS),
[b] Source: World Penn Table (Version 10.0),
[c] Source: Frankema (2010).

far-reaching land reform that affected half of Peru's agricultural lands and eliminated nearly every large-scale private holding by 1985.[7] The reform ultimately led to the redistribution of more than 10 million hectares of land, making it one of Latin America's most massive reforms in terms of agricultural land alongside Bolivia, Chile, Cuba, Mexico, and Nicaragua (Albertus, 2015; Albertus et al., 2020).

The reform was highly collectivist, with 90 % of expropriated land allocated to cooperative enterprises composed of former laborers from large-scale mechanized units along the coast and traditional *hacienda* estates in the highlands. These cooperatives functioned as indivisible production units, where land, machinery, and other productive assets were collectively owned, and management was carried out through elected governing bodies. However, participation was mandatory, and the law established measures to prevent land fragmentation. As part of this effort, the government retained land titles and maintained co-ownership of cooperatives until the land mortgages were fully repaid. Additionally, strict restrictions on land transfers were imposed, effectively shutting down land markets (Kay, 1982; Carter, 1984).

Land reform was intensively implemented from 1969 to 1976 when it expropriated 98 % of the agricultural land (Albertus et al., 2020). It then slowed after the coup d'état of 1975 and a severe late-1970s economic crisis, effectively coming to an end with the return to democracy in 1980. In response to peasant pressure, the new democratic regime enacted Decree Law # 02 in 1980, which allowed the subdivision of existing cooperatives into individually owned farms for former members. The law triggered a wave of cooperative dissolutions throughout the early 1980s, as many cooperatives collapsed amid severe financial problems and internal conflicts over profit-sharing and labor organization, ultimately fragmenting into single-unit family farms. By 1985, parcellation had affected approximately three-fourths of coastal cooperatives, with a similar trend observed among Andean collectives (Carter and Alvarez, 1989).

Peru's land reform was embedded within a broader urban-industrial development strategy that marginalized agriculture in favor of import-substitution industrialization. The agrarian reform was expected to serve multiple functions, including generating capital for industrial expansion and keeping food prices low for urban areas. As Carter and Alvarez (1989) note, agrarian cooperatives operated within a larger economic model that treated agriculture as a secondary subsystem, heavily influenced by macroeconomic policies. These policies included direct interventions in agriculture—such as price controls, taxation, import subsidies, marketing restrictions, and biased credit allocation—as well as broader macroeconomic measures like exchange rate manipulation, fiscal policies, and trade regulations, which indirectly affected the sector. As Kay (1982) argues, this policy framework discouraged investment, eroded profitability, and stifled productivity and employment growth in agriculture. In summary, from their creation, reform enterprises were subordinate to extractive policies designed to channel resources into industrial capital accumulation. Economic liberalization in the early 1980s failed to reverse agriculture's unfavorable macroeconomic environment.

Land reform drastically transformed the country's legal and economic conditions for land ownership and farm management, undeniably altering agricultural production processes and efficiency levels. However, the ultimate impact of Peru's land reform on national agricultural productivity remains a question of great importance. Previous research, despite its enormous scope and importance, has yet to provide solid and systematic evidence for quantifying the aggregate productivity impact of Peru's land reform and its trajectory over time.[8] The unavailability of consistent and comparable data and the lack of analytical tools precluded any conclusive analysis in this regard, as recognized by several scholars (Caballero and Alvarez, 1980; Saleth, 1991).

Nonetheless, informative analyses conducted after the reform reveal a disagreement over its productivity effects. While Saleth (1991) argues that the reform restructured and modernized the agricultural sector without disrupting productivity, others contend that production and productivity growth fell short of expectations and failed to meet even minimal targets (Caballero and Alvarez, 1980; Matos Mar and Mejía, 1980). In other studies, Kay (1982) and Caballero (1980) question the efficiency of reform enterprises, citing severe management problems within some cooperatives and structural contradictions arising from the broader economic model, though lacking the data to quantify their impact. Meanwhile, micro-level studies—primarily focusing on coastal cooperatives—provide no clear consensus on productivity outcomes (Carter, 1984; Horton, 1977; McClintock, 1981), documenting both successes and failures among cooperatives. Ultimately, this debate remains unresolved. The remainder of this paper outlines the first attempt at quantifying the impact of Peru's land reform on national agricultural productivity.

4. Empirical strategy

This article aims to evaluate the impact of Peru's land reform on national agricultural productivity. However, quantifying its aggregate effect presents a challenge, as we cannot directly observe how Peru's productivity would have evolved without the reform. To address this, we construct a counterfactual productivity trend using a pool of "donor"

[7] The law instituted landholding ceilings at or below 150 ha and legalized the expropriation of land, capital assets, and animals on properties larger than the stipulated ceiling

[8] Recently, scholars have conducted more credible assessments of Peru's land reform, although their focus extends beyond productivity. Albertus (2019), Albertus et al. (2020), Albertus and Popescu (2020), and Espinoza et al. (2020) utilize original local-level data on expropriations, exploiting variations in land reform intensity, location, and timing to examine some of its local impacts in the long run. They found that land reform reduced civil conflict but also resulted in decreased human capital accumulation and reduced economic and social mobility. However, their studies do not shed light on the productivity effects of the reform, even though this could be one of the critical underlying mechanisms contributing to these impacts.

countries that were not affected by the reform but shared similar pre-reform characteristics with Peru. We then compare Peru's actual post-reform productivity against this counterfactual scenario to estimate the reform's overall impact.

Our empirical approach follows the synthetic control method (SCM) developed by Abadie and Gardeazabal (2003), and Abadie et al. (2010, 2015) for comparative studies. The method has been recognized as one of the more important innovations in the policy evaluation literature in recent years (Athey and Imbens, 2017). The SCM provides a data-driven procedure to select a combination of comparison units (countries, states, etc.) that best resemble the characteristics of the unit of interest in terms of pre-treatment values of the outcome and other predictors. The method builds on the idea that, when the units of analysis are a few aggregate entities, a combination of unaffected units often provides a better comparison than any single unit alone (Abadie, 2021).

Formally, if X_1 is the vector of covariates in the treatment country (considering the outcome and selected predictors), X_0 is the matrix of covariates for all pre-selected counterfactual countries C in the donor pool, and W denotes the vector of individual country weights w_c, with $c = 1, \ldots, C$, the optimal weighting vector W^* is chosen to minimize the following mean-squared error over the pre-intervention period:

$$(X_1 - X_0 W)' V (X_1 - X_0 W) \tag{1}$$

subject to $\sum_{c=1}^{C} w_c = 1$ and $w_c \geq 0 \ \forall c$. The elements of V, a positive-semidefinite and symmetric matrix, are calculated using a data-driven approach.

The method then uses a weighted average of corresponding post-treatment data from the comparison units to approximate the counterfactual outcome of the exposed unit in the absence of the event or intervention. If Y_1 is the observed outcome for Peru and $Y_0 W^*$ is the synthetic control outcome derived from donor countries, the effect of the intervention is computed as the difference between the actual and counterfactual outcome, $Y_1 - Y_0 W^*$, over the postintervention period.

A measure of the goodness of fit of the synthetic unit to the observed treated unit, and the one that we follow in this paper as a criterion to rank alternative computational methods, is the preintervention mean-squared prediction error (Pre-MSPE). A smaller Pre-MSPE indicates a better fit. Conversely, the postintervention mean-squared prediction error (Post-MSPE) provides us an approximate measure of the effect of the intervention or event and can be interpreted as a natural assessment of the quantitative effect of the treatment.

Since the development of this method by Abadie and his colleagues, several extensions have been proposed to relax certain assumptions or account for imperfect balance. Ben-Michael et al. (2021) introduced the Augmented SCM, which employs an outcome model correct for any bias arising from imperfect pre-intervention fit. Similarly, Klößner and Pfeifer (2015) and Becker and Klößner (2018) extended the original SCM framework to introduce the Multivariate Synthetic Control Method using Time Series (MSCM-T). This method incorporates the entire time series of predictors rather than just averages, potentially providing a more refined counterfactual. We implement these extensions alongside the classic approach by Abadie and colleagues to assess the robustness of our findings, ensuring that our results do not hinge on a single methodological variant.

5. Data and variables

To evaluate the impact of Peru's land reform on national agricultural productivity, we leverage publicly available, country-level time series data on agricultural productivity and other economic predictors of productivity. This dataset, compiled and maintained by the USDA Economic Research Service (USDA-ERS), is accessible to researchers and enables the construction of a balanced panel comprising Peru and a set of potential comparison countries.

5.1. Measures of agricultural productivity

We primarily use agricultural output per worker (labor productivity) as a metric of factor use efficiency and a key indicator of economic performance in agriculture (Hayami, 1969; Mundlak, 2001; Restuccia et al., 2008; Gollin et al., 2014). Land productivity is less correlated with GDP per capita and can be distorted by variations in land availability and quality. While Total Factor Productivity (TFP) offers a more comprehensive metric by incorporating land, labor, machinery, and other inputs, comparable cross-country data on absolute TFP levels are unavailable. However, TFP indices do exist, enabling relative comparisons of growth rates rather than direct assessments of absolute productivity differences across countries.

The data come from the USDA Economic Research Service's International Agricultural Productivity (IAP) database, which compiles consistent, internationally comparable time series data on agricultural output, TFP growth rates, and information on various inputs, including land, labor, capital, and materials used in farm production for a wide range of countries starting from 1961. This dataset is sourced from UN organizations, particularly the Food and Agriculture Organization (FAO) and the International Labor Organization (ILO), and is supplemented with data from national statistical agencies, business organizations, and published academic studies.[9]

Labor Productivity is calculated as the amount of agricultural output produced per 1000 economically active people in agriculture. Gross agricultural output includes the value of production of 189 crop and livestock commodities, evaluated at constant 2004–06 global-average prices and measured in international 2005 dollars. The labor component considers the headcount of adults whose primary economic activity is in agriculture.[10] Despite the limitations noted, we also considered land productivity and TFP growth in supplementary checks to test the robustness of our findings.[11]

Given the complexities of measuring output and input variables in the context of Peru's 1970s collectivist reform, ensuring precision and validity of the data used was particularly important. To validate the productivity indicators provided by USDA-ERS, we conducted cross-checking analyses using independent data sources. First, we compared USDA labor productivity figures for Peru with agricultural value added per worker, sourced from Peru's National Accounts Statistics and compiled by the Groningen Growth and Development Centre Sector Database (Timmer et al., 2015). Both series exhibited a highly similar trend from 1961 to 1985, with a correlation coefficient exceeding 0.70. Additionally, we validated agricultural labor input figures by comparing USDA data for Peru with estimates from the Regional Employment Program for Latin America and the Caribbean PREALC, 1982). The results showed a strong correlation of 0.97, further reinforcing the consistency of our productivity measures.

[9] For a detailed description of the USDA data and methodology, please refer to https://www.ers.usda.gov/data-products/international-agricultural-productivity/documentation-and-methods/.

[10] This measure includes hired labor and unpaid family labor, full-time and part-time workers, but it may exclude some seasonal workers whose primary occupations are non-agricultural. Adults are defined as those aged 15 or older.

[11] Land productivity is measured as the ratio of total gross agricultural output to total agricultural land (in hectares). Land area is expressed in "rainfed cropland equivalents," which adjusts for differences in land quality based on irrigation status and land type (cropland or pasture). Idle land is excluded from the calculation. The Total Factor Productivity (TFP) index is defined as the ratio of total agricultural output to total inputs. TFP changes over time are measured by comparing the rate of change in total output with the rate of change in total input. Inputs included in TFP calculations are quality-adjusted land, labor, machinery power, livestock capital, synthetic NPK fertilizers, and animal feed, with weights assigned based on factor cost shares. TFP growth rates are derived from an index with a base year of 1961.

5.2. Agricultural productivity predictors

In addition to agricultural productivity, we compiled data on economic predictors of productivity from various publicly available sources, including the World Penn Table and USDA IAP data product. The SCM literature emphasizes the importance of synthetic control designs that take into account other predictors alongside pre-intervention outcomes. This approach is more accurate as it helps reduce the so-called bias bound by considering a broader range of factors (Abadie, 2021).

Influential studies, such as those by Hayami (1969), Hayami and Ruttan (1970), and Kawagoe et al. (1985), categorize agricultural productivity differences into three main groups: a) resource endowments, b) technology (which includes fixed or working capital and other technical inputs), and c) human capital. These categories reportedly account for more than 90 % of the productivity gap between the developing and developed world.

Therefore, we considered six predictors of agricultural productivity linked to the three broad categories outlined above. To account for resource endowments, we included a man/land ratio measure reflecting available agricultural labor per unit of land, following Nguyen (1979). For assessing the degree of access to agricultural capital and technical inputs in a country, we selected three variables: the machinery/land ratio, similar to Nguyen (1979); the fertilizers/land ratio, indicating the intensity of intermediate input usage; and GDP per capita, measuring comprehensive capital not covered for by the other variables, following Binswanger et al. (1987). To address the human capital category, we chose Barro and Lee (2010) index of human capital. Furthermore, we incorporated a measure of land inequality to compare countries with similar farmland distribution, considering the work of Vollrath (2007). The land Gini coefficient, calculated by Frankema (2010), captured this dimension. Detailed information on each variable, including data sources and definitions, is provided in Table 1.

The selection of six economic predictors was based on their ability to explain various measures of agricultural productivity. We confirm their relevance by analyzing the correlation between labor productivity and each predictor. Fig. A.1 in Appendix A reveals a strong and significant association between average productivity and the average value of the chosen predictors across a worldwide sample of 101 countries over the pre-intervention period (1961–1968).

5.3. Cross-country panel sample and intervention period

We assembled a panel dataset of countries by merging the outcome variables and economic predictors outlined above. This data comprises information from the USDA IAP dataset, covering 170 countries, and the World Penn Table, which includes 107 countries. The resulting matched sample, with complete data on the outcomes and predictors, encompasses 101 countries. However, due to the availability of land inequality data from Frankema (2010) for only 82 of these countries, we imputed the missing cases with the median value of their respective geographic regions.[12]

The cross-country dataset used in this study covers information from 1961 onwards and includes a selected sample of 101 countries. As land reform in Peru started in June 1969, we defined the pre-intervention period as the years 1961–1968, and the post-intervention period as 1969–1985, spanning eight years before and 17 years after the reform. We limited the post-intervention period to the year 1985 because during the second half of 1980, Peru's economy experienced one of its most severe crises under the presidency of Alan García. Hyperinflation and a major recession affected all economic variables, including agricultural costs and, consequently, farm productivity.

6. Donor pool selection criteria

6.1. Selecting Latin American countries

When identifying potential comparison countries to construct a synthetic Peru unaffected by land reform, it is crucial to adhere to the guidance provided by the synthetic control literature. To minimize interpolation bias and overfitting, the literature recommends restricting the donor pool to units with similar characteristics to the treated unit (Abadie, 2021).[13] We adopt this approach by limiting the donor pool *ex-ante* to a plausibly comparable set of Latin American countries, which offer two key advantages. First, Latin American countries share similarities in terms of agricultural productivity predictors and exhibit comparable pre-treatment outcome levels. Second, they also share similar climatic and natural conditions, making them susceptible to recurring climatic shocks, such as the El Niño-Southern Oscillation.[14] Our final donor pool consists of 19 Latin American nations, though our findings remain robust even when expanded to a broader set of countries (see Section 7.3.4 for details).

Fig. 1 shows that Peru's agricultural productivity levels and six selected predictors closely match those of other Latin American countries. In contrast, developed nations in Europe, North America, and Oceania exhibit higher productivity and capital measures, while many African countries have notably lower values. Middle Eastern and North African (MENA) countries also tend to have lower human capital and labor/land ratios, and most Asian countries fall somewhere in between. However, Peru and other Latin American nations stand out for their markedly high levels of land inequality, a structural difference that sets them apart from the rest of the world.

6.2. Excluding countries with similar interventions

Following Abadie's (2021) guidelines, no donor country should have experienced an intervention similar to Peru's land reform during the study period. However, as illustrated and discussed in Fig. A.2 in Appendix A, many Latin American nations underwent partial or major reforms between 1960 and 1980.

To address this confounding factor, we excluded three countries that implemented significant land reforms during this period, as documented by Bhattacharya et al. (2019) and others (de Janvry, 1981; Lipton, 2009; Eckstein et al., 1978; Binswanger et al., 1995).[15] Specifically, we excluded Chile, where a major land reform took place in 1967; Ecuador, which had a prolonged experience of land reform between 1964 and 1983, albeit on a smaller scale; and Venezuela, which redistributed public and private lands to approximately one-third of farm families between 1960 and 1973. These exclusions were necessary to avoid the inherent influence of interventions closely resembling the subject of interest.

As a result, our final donor pool includes 16 Latin American

[12] We used the USDA classification, which includes seven regions: Africa (Developed), Africa (Sub-Saharan), Latin America, North America, Asia, Europe, Oceania, and WANA (West Asia and North Africa). Missing values in land Gini were mostly present in African countries and some Asian countries.

[13] Overfitting arises when the characteristics of the treated unit are artificially matched by combining idiosyncratic variations in a large number of unaffected units.

[14] Alternative analyses that incorporated climatic variables such as rainfall and temperature, sourced from Aquastat and World Bank CCKP data, as additional predictors of agricultural productivity yielded similar results.

[15] We also took measures to ensure that the selected pool of donor countries did not undergo any other significant policy measures or shocks that could have impacted their agricultural sectors. The smooth trajectory of productivity in most of the countries, as illustrated in Fig. A.2 in Appendix A, supports this idea.

Fig. 1. Balance across Productivity Measures and Predictors between Peru, Latin America, and Other Geographic Regions (average 1961–1968). Notes: The figure depicts the pre-reform average of three productivity indicators (log agricultural labor productivity, log agricultural land productivity, and the agricultural Total Factor Productivity (TFP) Index) and six predictors (log labor-to-land ratio, log machinery-to-land ratio, log fertilizer-to-land ratio, log GDP per capita, the Human Capital Index, and the land Gini coefficient) for Peru and 100 other countries grouped into seven USDA worldwide regions. For detailed descriptions of each predictor, see Table 1.

countries.[16] Most of the selected countries either did not undergo significant land reform at all (Argentina, Uruguay, Brazil, Haiti, and Trinidad and Tobago) or experienced marginal or partial reforms despite the support of the United States and its 'Alliance for Progress' (Colombia, Costa Rica, Dominican Republic, Honduras, and Panama). A few countries did undertake large-scale reforms, but these occurred either after the study period (El Salvador and Nicaragua) or beforehand (Mexico in the early 1930s; Bolivia and Guatemala in the early 1950s).

These exclusions help ensure that the donor countries' productivity trends were not substantially altered by comparable redistributive reforms and modifications in land rights during the study period. In Section 7.3.3, we show that our main results remain robust under alternative donor pools—excluding those that reformed land before 1960, in the late 1970s, or partially. The final synthetic counterfactual thus depicts the trajectory that Peru's agricultural productivity would likely have followed in the absence of its own reform.

7. Results

We present the results in five parts. First, we outline the procedure for constructing the productivity trend of a synthetic version of Peru using data from comparable Latin American countries. Second, we present the main findings and discuss their magnitude. Third, we conduct supplementary analyses to assess the robustness of our results and address potential inferential threats. Fourth, to gain deeper insights into the relationship between labor productivity, land productivity, and Total Factor Productivity, we undertake a resource decomposition analysis. Finally, we draw on micro-level studies and qualitative research to discuss the plausible key contributors to the reform's

[16] The complete list of countries is provided in Table A.1 in Appendix A, along with pre-reform average values of the selected measures of agricultural productivity and its predictors.

outcomes.

7.1. Constructing the synthetic control

We used synthetic control methods to construct a counterfactual scenario of the evolution of Peru's agricultural productivity in the absence of collectivist reform. As previously discussed, we restricted the donor pool to a set of 16 Latin American countries that are similar to Peru. The SCM uses data-driven procedures to construct this synthetic control group by searching for a weighted combination of donor countries chosen to approximate Peru in terms of pre-intervention productivity values and other productivity predictors.

We estimated a synthetic control group for each of the selected measures of agricultural productivity, following the nested optimization method as described by Abadie and Gardeazabal (2003) and Abadie et al. (2010, 2015).[17] We included three pre-treatment outcome lags and the pre-intervention average of the six productivity predictors as covariates.[18] To prevent assigning small or null weights to the other covariates, we avoided using all pre-treatment outcomes as separate predictors, following Kaul et al. (2022). The resulting weights allocated to each country, along with the pre-intervention model fit statistics, are presented in Table 2.

Table 2 displays the weights assigned to each country in the synthetic version of Peru across three measures of agricultural productivity. For labor productivity, the synthetic Peru is a weighted average of Bolivia, El Salvador, Mexico, Dominican Republic, and Trinidad and Tobago, with weights decreasing in that order. All other countries in the donor pool receive zero weights. In terms of land productivity, the synthetic Peru consists of the Dominican Republic, Brazil, and Honduras. Concerning TFP growth, the synthetic control group combines the two previous groups and includes Haiti, the Dominican Republic, Colombia, Trinidad and Tobago, and Bolivia. The reason for selecting distinct countries for each productivity metric lies in the method's emphasis on prioritizing a weighted combination of donor units that best replicates the outcome's preintervention trends.

Over the pre-intervention period, the root mean square predicted error (RMSPE) is very close to zero for the various outcome variables considered. For labor productivity, the RMSPE represents only 2.9 % of the mean pre-intervention labor productivity. A similar relative size of the RMSPE is observed for the synthetic versions of land productivity and TFP growth. As we will see in the next subsection, these synthetic control groups accurately replicate the pre-reform agricultural productivity trajectory for Peru.

Table 3 compares the pre-reform characteristics of Peru with those of the synthetic Peru and the Latin American donor pool, for the case of labor productivity. Overall, these findings indicate that the synthetic Peru provides a much closer match to Peru than the average of other Latin American countries in the donor pool. The synthetic Peru closely resembles actual Peru in terms of pre-reform labor productivity levels, machinery/land ratio, fertilizer/land ratio, GDP per capita, and human capital. In most cases, the standardized mean difference between Peru and its synthetic counterpart is below 0.1, although for the labor/land ratio, this metric is slightly higher. Additionally, due to Peru's high levels of land inequality during the pre-reform period, this variable cannot be perfectly fitted using a combination of the comparison countries.

Table 2
Estimated synthetic control weights for each outcome variable.

Country -Weights (W)	Labor Productivity	Land Productivity	TFP index
Bolivia	0.420	0	0.018
Brazil	0	0.358	0
Colombia	0	0	0.202
Dominican Republic	0.046	0.561	0.302
Honduras	0	0.081	0
Haiti	0	0	0.375
Mexico	0.092	0	0
El Salvador	0.400	0	0.002
Trinidad and Tobago	0.042	0	0.101
Model fit			
Pre-intervention RMSPE	40.0	34.1	2.9
Pre-intervention RMSPE (%)	2.9 %	4.1 %	2.9 %

Notes: RMSPE stands for Root Mean Squared Predicted Error. Pre-intervention RMSPE (%) indicates the average pre-intervention RMSPE as percentage of the pre-intervention outcome value for Peru.

7.2. The impact of Peru's land reform on agricultural productivity

Panel A of Fig. 2 illustrates the labor productivity trends of Peru and its synthetic counterpart from 1961 to 1985. The synthetic Peru closely mirrors the labor productivity trajectory of actual Peru during the pre-reform period. This alignment is a crucial aspect that supports the credibility of the synthetic control estimator, in accordance with Abadie (2021). The close match in pre-reform labor productivity between actual and synthetic Peru, along with their similarity regarding productivity predictors (as shown in Table 3), further suggests that a combination of other Latin American countries can accurately reproduce the economic attributes of Peru before land reform.

The estimate of the impact of Peru's reform on labor productivity is drawn from the difference between Peru and its synthetic counterpart during the post-reform period, as depicted on the right side of Panel A in Fig. 2. The evolution of the estimated gap between the two series is

Table 3
Pre-intervention balance across predictors of labor productivity between Peru, synthetic Peru, and average Latin America.

Covariates	Peru	Synthetic Peru	Latin America	SMD Synth	SMD LA
Outcome lags					
Labor productivity (1961–1964)	1329	1329	2889	0.00	−0.49
Labor productivity (1965–1967)	1409	1391	3064	0.01	−0.51
Labor productivity (1968)	1337	1378	3316	−0.01	−0.56
Predictors					
Labor/land ratio (1961–1968)	0.73	0.53	0.42	0.88	1.37
Machinery/land ratio (1961–1968)	3.41	2.99	4.88	0.07	−0.27
Fertilizer/land ratio (1961–1968)	36.90	36.98	26.80	0.00	0.29
Log GDP per capita (1961–1968)	8.67	8.50	8.53	0.37	0.30
Human Capital Index (1961–1968)	1.54	1.47	1.56	0.26	−0.08
Land Gini (circa 1960)	85.40	75.49	73.68	1.05	1.24

Notes: Columns 1–3 present the pre-intervention averages for three labor productivity lags and six productivity predictors for Peru, its synthetic version (based on country weights showed in column 1 of Table 2), and 16 selected Latin American countries. Column 4 reports the Standardized Mean Difference (SMD) between Peru and Synthetic Peru, while column 5 reports the SMD between Peru and the Latin America average. SMD were calculated using the Latin American standard deviation across country averages.

[17] The analysis was conducted using Stata software with the *synth* command, including the *nested* option. This command employs a fully nested optimization procedure that searches among all diagonal positive semidefinite V-matrices and sets of W-weights to determine the best-fitting convex combination of the control units.

[18] As TFP is expressed as an index, we included pre-intervention average labor productivity as an additional predictor. This was done to help select donor countries with similar pre-reform productivity levels.

presented in Panel B. The gap between actual and counterfactual labor productivity widens from approximately zero during the pre-intervention period to over −30 % by the end of the analyzed period. We anticipated that land reform in Peru would have a null or positive effect on labor productivity during the first few years immediately following the reform due to the significant support provided to agricultural cooperatives during this initial period.[19] Indeed, between 1969 and 1971, labor productivity in Peru averaged 3 % higher than its synthetic version. The year 1972 marked a clear turning point, as labor productivity in Peru began to decrease while that of its synthetic counterpart continued to increase. Consequently, the gap in labor productivity rapidly expanded from −8 % in 1972 to −44 % in 1980. Then, this difference reduced to an average annual percentage of −26 % during the 1981–1985 period, coinciding with the enactment of decree law 02 at the end of 1980 that led to the dissolution of the cooperatives.

Our findings indicate a substantial adverse impact of Peru's collectivist reform on labor productivity. Over the entire 1969–1985 period, agricultural output per 1000 workers decreased by an average of 270 international 2005 dollars per year, equivalent to roughly 20 % of the 1968 baseline level. While a small recovery is observed starting in 1980, following the initial stage of decollectivization, the productivity losses couldn't be reversed by the end of the study period.

A similar analysis was performed for the chosen measures of land productivity and TFP growth. Fig. 3, Panel A, depicts the gap in land productivity between Peru and its synthetic counterpart, while Panel B displays the difference in the TFP index. In both cases, the pre-reform divergence between the actual and synthetic series is small, averaging 4.1 % of Peru's land productivity and 2.9 % of the TFP index during the 1961–1968 period. These pre-reform fits are reasonably small and similar to what was observed for the synthetic version of labor productivity.

The unshaded portion of Panel A in Fig. 3 displays the yearly estimates of the impacts of Peru's land reform on land productivity, representing the yearly gaps in agricultural output per hectare between Peru and its synthetic counterpart during the post-reform period. Our findings suggest that reform had a large negative effect on land productivity, and this effect intensified over time. The most substantial adverse impact is observed in 1983 when land productivity in Peru decreased by 43 % compared to its counterfactual version not affected by the reform. Overall, our estimates indicate that between 1969 and 1985, Peru experienced an annual loss in land productivity equivalent to 21 % of the 1968 baseline level.

In Panel B, we present corresponding results using the TFP index as an outcome measure. Since this measure captures changes in growth rates rather than absolute TFP levels, the comparison between Peru and its synthetic counterpart reflects relative shifts in productivity trends. The findings indicate that Peru's TFP index declined by an average of 13 % relative to its synthetic version between 1969 and 1985. The sharpest contraction occurred in 1980, with TFP falling 30 %, aligning with the observed labor productivity decline. The reform particularly slowed TFP growth between 1975 and 1980, during which the index remained approximately 20 % below the synthetic control. By the end of the study period, TFP losses had moderated, with productivity remaining around 10 % below the counterfactual.

7.3. Robustness and inferential threats

This section addresses several potential threats to identifying the causal effect of land reform on agricultural productivity. First, we assess the significance of the SCM estimates by conducting a placebo test. Then, we explore the sensitivity of our results to changes in the optimization method used for selecting country and predictors weights. We then examined the robustness of our findings to changes in the donor pool of countries, both considering alternative donor pools that exclude nations that underwent major or partial land reforms and expanding the donor pool to include countries beyond Latin America. Finally, we ensure that our results are not driven by broader economic trends, as no comparable productivity effects are observed in other sectors of the economy.

7.3.1. In-space placebo test

This test aims to determine if the results we obtained could be attributed to chance. Following Abadie and Gardeazabal (2003) and Abadie et al. (2010), we conducted an "in-space" placebo test by iteratively applying the synthetic control method used to estimate the effect of Peru's land reform to every other country in the donor pool. The main idea is that if the magnitude of the impact of land reform in Peru is robust, similar impacts should not be observed in other comparable countries that were not affected by this reform. This procedure provides us with a distribution of estimated gaps for the countries where no intervention took place.

Fig. 4 displays the results of the placebo test. The grey lines indicate the gap in labor productivity associated with each of the countries in the donor pool that were not subject to Peru's land reform.[20] The blue line denotes the gap estimated for Peru. It is apparent from the figure that the estimated gap for Peru during the post-reform period is unusually large relative to the distribution of the gaps for the countries in the donor pool. This finding suggests that land reform in Peru had a significant impact on labor productivity.

7.3.2. Alternative optimization methods

Another important aspect to consider is the sensitivity of the results to the choice of the optimization method used to determine the weights assigned to each country and productivity predictors. As outlined in the methodological section, several optimization advances have been developed recently to improve the accuracy of the synthetic control's outcome pre-treatment fit and predictor balance. We aim to assess whether our selected method (i.e., nested SCM) produces similar results to alternative algorithm techniques. In Fig. B.1 in Appendix B, we provide results using three alternative methods in addition to our selected method. The methods are classic SCM (not-nested), Multivariate Synthetic Control Method using Time Series (Becker and Klößner, 2018), and Augmented Synthetic Control Method (Ben-Michael et al., 2021). The results are similar regardless of the chosen method, with both the outcome pre-treatment fit and post-treatment divergence being comparable across the examined approaches.

7.3.3. Excluding countries that underwent land reform from the donor pool

Another concern relates to the possibility that some nations included in the donor pool are unsuitable as comparison units because they underwent major or partial land reforms before or during the study period. As discussed in Section 6.2, even after excluding the cases of major land reforms in Chile, Ecuador, and Venezuela, most of the remaining

[19] By 1971, approximately 1.9 million hectares (28 % of the total amount expropriated) had been expropriated by the reform. During this initial phase, the reform predominantly affected the coastal area, where many modern, export-oriented, and highly capital-intensive farms were located. The coastal system specialized in the production of sugar, rice, and other industrial crops or primary transformation such as cotton, grapevine, and citrus. The military government made significant efforts to support these farms to ensure a smoot transition to a cooperative system without disrupting production levels (Caballero and Alvarez, 1980; Matos Mar and Mejía, 1980).

[20] For illustration purposes, Fig. 4 excludes six countries with poor pre-intervention fit. The interpretation of the findings does not change upon the inclusion of these countries. In fact, excluding synthetic Argentina and Haiti (which exhibit the worst pre-intervention fit, 15 % for Argentina and 53 % for Haiti), synthetic Peru is the one with the highest post-intervention RMSPE at 22.8 %.

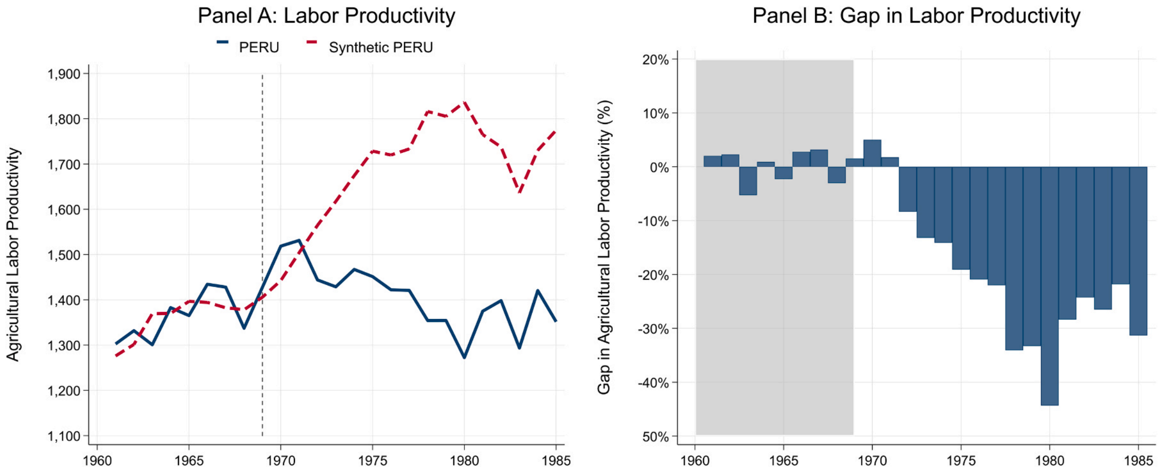

Fig. 2. Labor productivity in Peru and synthetic Peru. Notes: In Panel B, we report the difference in labor productivity between Peru and its synthetic version. This gap is expressed as percentages concerning the labor productivity value of actual Peru. The vertical dashed line in Panel A and the shaded area in Panel B indicate the pre-reform period. Pre-reform RMSPE: 40 (2.9 %). Post-reform RMSPE: 322 (22.8 %).

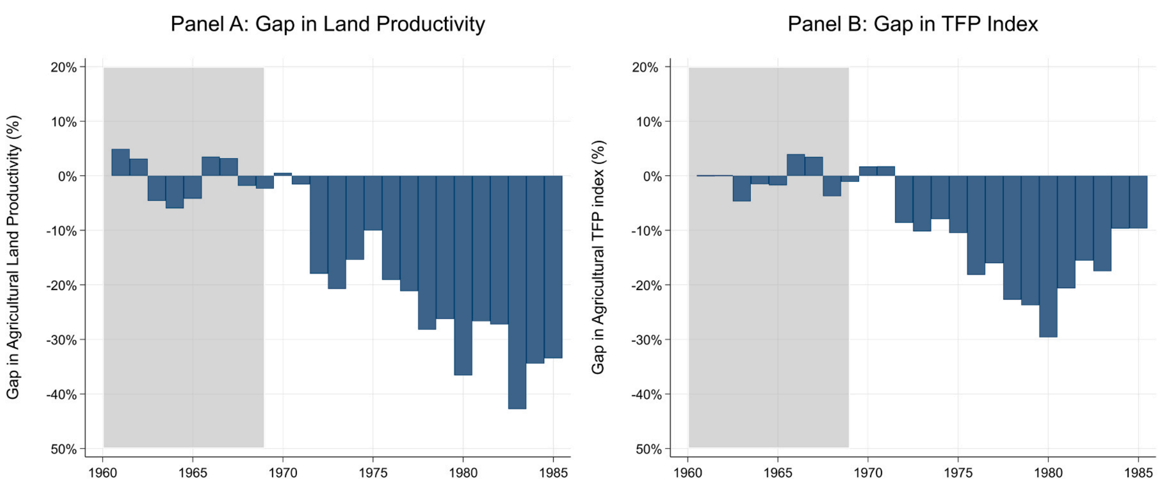

Fig. 3. Land productivity gap and TFP growth gap between Peru and synthetic Peru. Notes: Panel A and B report the difference between Peru and its synthetic version concerning land productivity and the TFP index, respectively. The gaps are expressed as percentages concerning the outcome value of actual Peru. The shaded area in both plots indicates the pre-reform period. Pre-reform / Post-reform RMSPE (%): Land Productivity (4.1 %/23.5 %), TFP index (2.9 %/14.8 %).

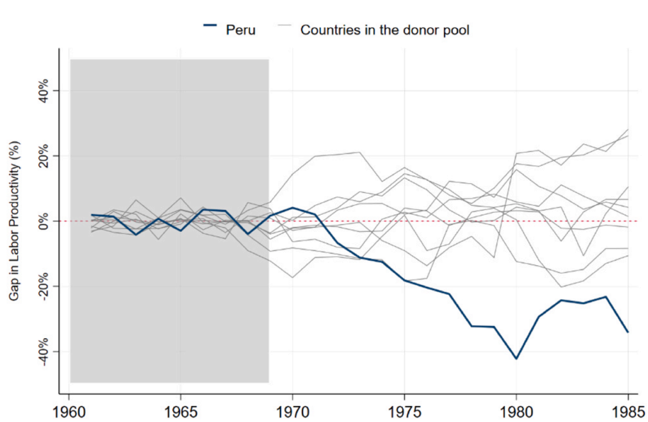

Fig. 4. Placebo test for labor productivity. Notes: The figure depicts the difference between Peru and its synthetic version in terms of labor productivity (blue line), as well as the same difference for countries in the donor pool with a pre-intervention fit below 5 % (grey lines).

countries in the donor pool also witnessed the enactment of land reform laws. Consequently, the influence of interventions alike the one under investigation could potentially bias our results. In the following lines, we discuss the reason why we believe this is not the case and provide supporting evidence.

First, it can be argued that Mexico, Bolivia, and Guatemala are unsuitable as comparison countries because they undertook major land reforms prior to the study period, and thus, they had already experienced a structural transformation in land distribution and other aspects associated with these reforms. While it is possible that the productivity in these countries may have been affected by land reform in the past, it is unlikely that the effect of these reforms manifested itself during the period under study and distorted post-1960 productivity trends. Nevertheless, in Panel A of Fig. B.2 in Appendix B, we ran as a robustness exercise excluding these three countries from the donor pool, and the results remained unchanged.

Second, the donor pool also comprised Nicaragua and El Salvador, both of which underwent land reform between 1979 and 1981. We decided to keep these countries in the donor pool because the potential effect of their reforms would only come into play at the end of the study period, without affecting the critical periods before (1961–1968) and during (1969–1979) land reform in Peru. In Panel B of Fig. B.2, we demonstrated that out results are also robust to excluding these two countries from the donor pool. Also, in Panel C, we showed that the results hold even after removing the five countries excluded in Panel A and B.

Third, one might argue against the appropriateness of utilizing a donor pool that includes the six countries that underwent partial or marginal land reforms, as these attempts may have still influenced their productivity trends during the study period. As depicted in Fig. A.2 in Appendix A, this does not appear to be the case, as the productivity trajectories of these countries remained unaffected after the implementation of reforms. Nevertheless, Panel D of Fig. B.2 demonstrated that our results barely change much even when also excluding these six nations from the donor pool.

7.3.4. Expanded donor pool beyond Latin American countries

We also examine the robustness of our results to changes in the donor pool of countries. As explained before, we selected a donor pool made up of Latin American countries unaffected by land reform during the study period, based on their similarities to Peru concerning pre-reform agricultural productivity values and productivity predictors. However, as illustrated in Fig. 1, there are countries from other regions that also share comparable characteristics with Peru in terms of such dimensions. Therefore, we replicate the results for labor productivity using an expanded donor pool that also includes Asian and African countries. North American, European, and Oceanian countries were excluded given their distinctive characteristics. Fig. B.3 in Appendix B indicate a similar negative impact of Peru's land reform on labor productivity, while also achieving a small and comparable pre-treatment outcome fit.[21] Hence, these findings suggest that our results are not driven by the choice of the donor pool of countries.

7.3.5. Trends in Peru's overall economy at the time of reform

Another key concern is whether the observed changes in agricultural productivity resulted from broader economic trends rather than from agrarian policies specifically targeting the sector, including collectivization and extractive policies. Between 1968 and 1975, the military government led by General Velasco engaged in a series of significant reforms aimed at achieving a 'structural transformation' of the Peruvian economy and society. This involved a fundamental restructuring of asset ownership in favor of the public sector and a substantial expansion of the state's role in the economy. These reforms reached various strategic sectors beyond agriculture, including industry, banking, trade, fishing, education, and mining (Thorp and Bertram, 1978). It is therefore possible that the observed changes in agricultural productivity are the result of policy measures that affected the performance of the overall economy rather than the agricultural sector alone. We investigate this possibility by conducting additional analyses that that separate common economic effects across all sectors from the specific impact of land reform on agriculture.

We begin by examining the trends in GDP per capita in Peru before and after land reform to assess whether this timeframe coincides with important changes in the country's economy and overall productivity.[22] Once again, we employ a synthetic control method approach to benchmark Peru's GDP per capita trajectory against a synthetic counterfactual path, using a similar procedure and the same donor pool employed in our baseline results.[23] The intervention period is the same as before, with treatment starting date set in 1969. The outcome variable is the real GDP per capita at constant millions of 2017 USD, sourced from the World Penn Table.

Fig. 5 presents the results of this analysis. As shown in Panel A, the trends of GDP per capita for Peru and its synthetic version follow an increasing and similar pattern prior to 1969, with minimal divergence between the two series during this timeframe (pre-reform RMSPE around 1 %). This pattern and close fit persist between 1969 and 1975, spanning the period of land reform and the aforementioned policy changes. It is not until 1976 that we observe a divergence between the two trends, with Peru's GDP per capita declining in 1976–1978 and then increasing in 1979–1981, while synthetic Peru followed an opposite path that ultimately converges with actual Peru in 1981. Thereafter, both series depict a declining pattern, reflecting the negative external and supply shocks that impacted Latin America during the "lost decade" of the 1980s.

As a result, the gap between actual and counterfactual GDP per capita for Peru during the post-reform period is small (shown in Panel B), averaging 5.6 % between 1969 and 1985. The negative gap observed from 1977 to 1980 can hardly be attributed to policy changes that occurred several years earlier. This finding suggests that the adverse effects on productivity are specific to the agricultural sector rather than a broader economic downturn.

We conducted a supplementary analysis looking at the productivity trends within the non-agricultural sector to investigate this aspect in further detail. The results, outlined in Fig. B.4 in Appendix B, indicate a diverging trend between both sectors shortly after land reform started. While productivity contracted in the non-agricultural sector, it expanded in the rest of the sectors. These findings suggest that the negative trends in agricultural productivity cannot be attributed to common economic fluctuations but are instead more likely driven by land reform, which represented the most significant structural shift in the agricultural sector. This underscores the role of land collectivization and extractive policies as key contributors to the sector's productivity decline, rather than broader macroeconomic trends affecting the economy as a whole.

7.4. Labor and land productivity decomposition

Our findings reveal a robust and large adverse effect of Peru's land reform on the country's agricultural productivity. This impact is observed across the three measures of agricultural productivity, albeit with certain intricacies related to the timing and extent of the impact. To gain a deeper understanding of how land reform affected both labor and land productivity, along with its interplay with TFP, we undertook a resource decomposition analysis.[24] This exploration delved into the sources of labor and land productivity growth over the post-reform period, specifically by disentangling the relative contributions of changes in TFP and changes in the intensity of use of other inputs. We applied this methodology not only to Peru but also to its synthetic counterpart, serving as a benchmark for comparison.[25]

Panel A in Fig. 6 depicts the decomposition of the average annual growth rate of labor productivity for the period 1969–1980, while Panel

[21] Although the RMSPE achieved by the synthetic Peru using the extended pool of donor countries is slightly smaller than the one using the Latin American donor pool, a better fit in pre-reform outcome trends comes at the cost of larger imbalances concerning productivity predictors. The synthetic version of Peru that includes Asian and African countries shows greater differences with Peru than the Latin American synthetic version in most of the predictors of agricultural productivity.

[22] Agriculture contributed less than 8 % to Peru's overall GDP from 1960 to 1980. Consequently, the trends in GDP per capita primarily capture those observed in the non-agricultural sector.

[23] In this case, we used three pre-intervention outcome lags and four economic predictors: the human capital index, terms of trade, openness, and the share of gross capital formation.

[24] Refer to Appendix C for further details on this procedure.

[25] The calculation for synthetic Peru was conducted using the donor weights as presented in column 1 of Table 2. The results remain consistent when alternative weights are utilized, as indicated in column 2 and 3 of Table 2.

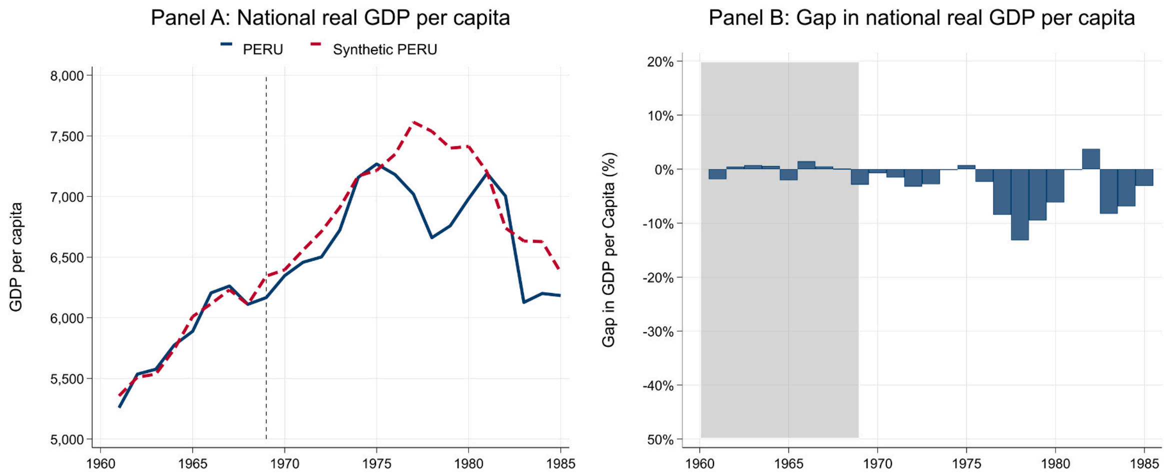

Fig. 5. GDP per capita in Peru and synthetic Peru. Notes: In Panel B, we report the difference in GDP per capita between Peru and its synthetic version. This gap is expressed as percentages concerning the GDP per capita value of actual Peru. The vertical dashed line in Panel A and the shaded area in Panel B indicate the pre-reform period. Pre-reform RMSPE: 68 (1.2 %). Post-reform RMSPE: 377 (5.6 %).

B provides the corresponding results for land productivity.[26] The growth rate of both productivity metrics (shown in the shaded rectangle) is broken down into input intensification (i.e., more capital, land, and fertilizer per unit of labor or land) and TFP growth, where TFP reflects the efficiency with which all inputs are converted into outputs. Enhancements in TFP stem from technological advancements, improved technical and allocative efficiency in resource utilization, and economies of scope. On the other hand, improvements in input intensification are primarily influenced by variations in resource endowments, migration patterns, prices, and terms of trade (U.S. Department of Agriculture, 2023).

The results shown in Fig. 6 suggest that the poor growth of labor and land productivity in Peru is mainly attributed to underperforming TFP growth. To illustrate, over the period spanning from 1969 to 1980, the average growth rate of land productivity exhibited a discouraging figure of −1.15 %. Within this value, the decline in TFP contributed −0.71 %, the reduction in the labor-to-land ratio contributed −0.32 %, and the changes in the intensity of utilization of other factors (such as machinery, fertilizers, livestock, and animal feed) contributed −0.12 %. Regarding labor productivity, its average growth rate during this period was −0.41 %, primarily explained by the decline in TFP growth (-0.71 %), but partially offset by the growth in the land-to-labor ratio (+0.25 %) and the higher intensity of utilization of other inputs (+0.04 %).

In addition, Fig. 6 reveals a contrasting trend in the TFP growth of Peru's synthetic version, which experienced a positive average annual growth rate of 1.6 % throughout the analyzed period. Consequently, labor and land productivity in synthetic Peru achieved growth rates of 2.2 % and 1.8 %, respectively. The difference in the average TFP growth rate between Peru and its synthetic counterpart reached −2.3 %, consistent with the observation of a negative impact of land reform on Peru's TFP presented in the previous sections. In contrast, changes in the intensity of utilization of other input factors, such as machinery, fertilizers, livestock, and animal feed, exerted a more modest influence on the average annual growth rate of labor and land productivity.

7.5. *Potential explanations*

Taken together, our findings indicate that collectivist land reform in Peru led to a substantial decline in agricultural productivity between 1969 and 1985, primarily due to reductions in Total Factor Productivity (TFP). Rather than limiting input access and availability, land reform appears to have adversely affected the overall efficiency of farm production. This could have arisen due to reductions in technical and allocative efficiency in resource utilization, disruption in technological adoption, or due to losses in economies of scope following collectivization.

While the study allows to produce illuminating quantitative results at the aggregate level, the nature of our macro-level approach does not provide insights into which structural factors at the micro-level were responsible for the aggregate changes. This prevent us from empirically disentangling the contribution of specific reform features or processes triggered by redistribution or complementary policies. However, insights from case studies and qualitative research provide useful perspectives on the underlying drivers of this productivity decline.

As previously discussed, the drop in TFP was likely influenced by the shift in farm management, transitioning from large private landowners to farmer cooperatives. Many coastal producer cooperatives faced severe management challenges, internal conflicts, and labor disincentives, as documented in various studies (Carter, 1984, 1987; Horton, 1977; McClintock, 1981). The financial crisis of cooperative farming and the massive wave of parcellation in the 1980s further reinforce this view. Additionally, extractive macroeconomic policies and market distortions within Peru's broader development strategy likely further constrained the agricultural sector (Kay, 1982; Carter, 1984; de Janvry and Sadoulet, 1989).

Other reform-related factors may have also contributed to these disappointing outcomes. One issue frequently cited in the literature is the lack of managerial experience among reform beneficiaries, exacerbated by the absence of policies ensuring a smooth transition in technology and technical knowledge transfer (Caballero and Alvarez, 1980; de Janvry and Sadoulet, 1989; Eckstein et al., 1978). Another major potential contributor is decapitalization prior to expropriation, as landowners anticipating confiscation dismantled infrastructure, removed machinery, and liquidated assets—especially livestock—as a form of resistance to reform (Kay, 1982; Matos Mar and Mejía, 1980; Saleth, 1991).

[26] The analysis primary focus on the period from 1969 to 1980, a time marked by significant land reform implementation. This timeframe allows us to isolate the impact of Decree Law 02, which allowed the individual subdivision of existing cooperatives starting in 1980.

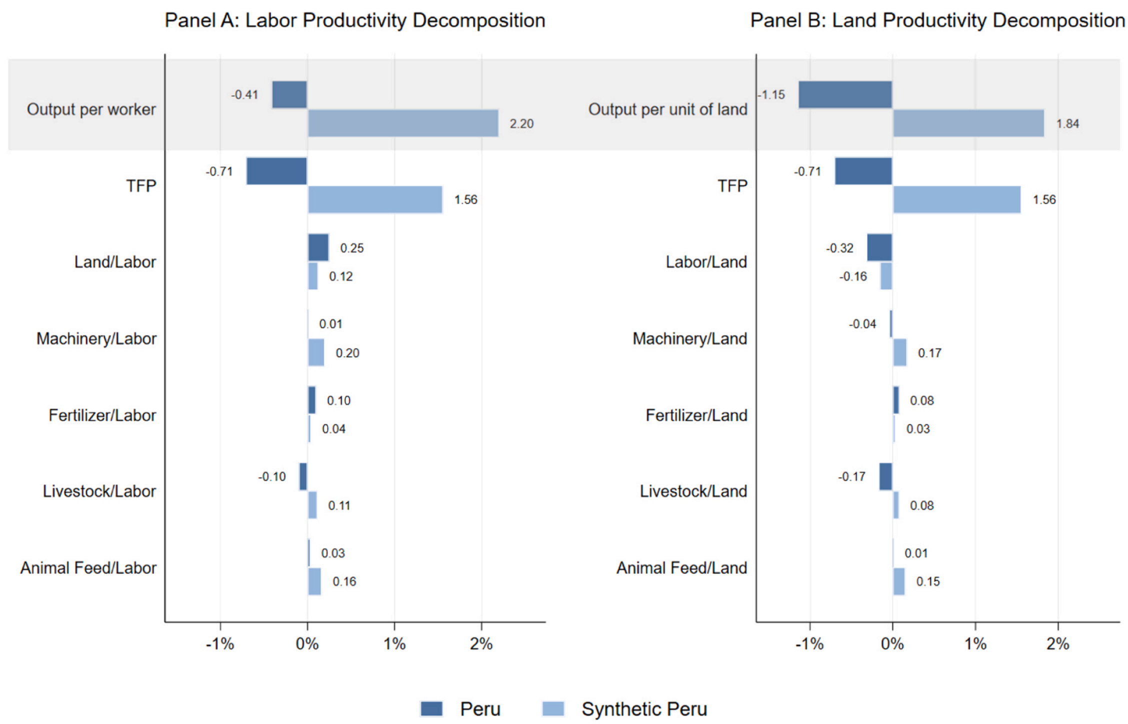

Fig. 6. Labor and land productivity growth decomposition (1969–1980). Notes: Panel A reports the decomposition of labor productivity growth, and Panel B reports corresponding results for land productivity growth over the post-reform period (1969–1980). These figures are reported for both Peru and its synthetic counterpart based on country weights shown in column 1 of Table 2. The shaded area at the top of both figures reports the average annual growth rate of labor and land productivity, while the rest of the y-axis categories break down these productivity growth rates into TFP growth and the intensification of other input factors.

8. Conclusions and discussion

The 20th century witnessed the emergence of significant land reform initiatives aimed at addressing extreme historical disparities in land-ownership access. Despite the prevalence of land reform across the developing world, only a few of these initiatives have undergone rigorous evaluation. We delve into the case study of Peru's land reform in the early 1970s to shed light on the impact of a major land redistribution policy that, rather than redistributing land to individual smallholders, primarily established collective forms of property rights.

Following the synthetic control method, we construct a suitable counterfactual for Peru in the absence of land reform using data from comparable Latin American countries unaffected by the reform, enabling us to examine the magnitude and time path of land reform's impact on national agricultural productivity. Our findings reveal a substantial negative impact of Peru's land reform on national agricultural productivity, with productivity remaining over 20 % below the synthetic control between 1969 and 1985. Several robustness analyses support the causal interpretation of these effects.

We attribute the reform's impact to decreases in the overall efficiency of farm production. Numerous factors explain the economic failure of this redistributive experience, including internal economic disincentives created by the cooperative system and external macroeconomic distortions. These findings align with studies emphasizing the critical importance of design, planning, and state capacity in the success of large-scale land reform initiatives.

Our results do not indicate, however, that economic or social benefits would have been greater if traditional *haciendas* has been left intact. In fact, evaluating land reform solely through the lens of productivity may be too narrow, as these initiatives were often driven by urgent social and political imperatives. Recent research highlights important non-economic effects of Peru's land reform. A recent study by Albertus (2019) unveiled a positive outcome of Peru's reform in mitigating violence during the terrorist era, underscoring its wider impact on societal stability. Likewise, Paredes (2023) demonstrated that the reform served as a catalyst for heightened local political engagement. These findings highlight that the reform's effects resounded well beyond economic realms, underscoring its intricate role in shaping both social and political landscapes.

It is essential to underscore that the Peruvian experience differs markedly from classical redistributive land reforms, which typically aim to transfer land ownership to smallholders rather than establish collective enterprises. As such, caution is warranted when extrapolating lessons from Peru's case to contexts involving traditional land-to-the-triller redistribution. Nevertheless, one broader conclusion that emerges is that rearranging land tenure alone is unlikely to succeed unless accompanied by complementary factors such as know-how, effective management, access to capital, and adequate market support. This finding resonates with the recent emphasis in the development literature on addressing multiple simultaneous productivity constraints (Deutschmann et al., 2025).

Land reform remains a politically salient issue in countries such as Brazil, Colombia, Namibia, the Philippines, South Africa, and Venezuela, where persistent land inequality, rural poverty, and renewed pressures for land redistribution continue to shape political debates (Albertus et al., 2020). As Albertus (2025) notes, popular demands for land redistribution and political pressures to address land inequality are expected to intensify in many parts of the world in the coming decades. In these contexts, the Peruvian experience provides valuable lessons. To maximize the benefits of land redistribution, reforms must be accompanied by policies that reinforce—rather than constrain—producer incentives and decision-making autonomy. Institutional frameworks that promote voluntary participation, self-determination, and strong local leadership, while avoiding excessive state control and extractive policies, are critical for enhancing the viability and long-term success of land reform initiatives.

CRediT authorship contribution statement

Mauricio Espinoza: Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Javier Escobal:** Supervision, Investigation, Conceptualization.

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Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT to assist with proofreading the language of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Declaration of Competing Interest

The authors declare that there is no conflict of interest when developing this manuscript.

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Appendix A. Descriptive tables and figures

Table A.1
Peru and donor pool pre-reform (1961–1968) average values of productivity measures and its predictors

	Outcomes			Predictors					
Country	Labor Prod.	Land Prod.	Ag. TFP index	Human Capital	Capital/ Land	Labor/ Land	GDP per capita, ln	Fertilizer/ Land	Land Gini
Peru	**1360**	**832**	**99**	**1.54**	**3.41**	**0.73**	**8.67**	**36.90**	**85.40**
Argentina	11,636	653	105	2.01	7.67	0.07	9.53	1.69	81.40
Bolivia	1015	297	107	1.55	1.21	0.46	8.51	10.14	76.80
Brazil	1960	673	100	1.45	3.51	0.39	8.49	9.74	78.70
Colombia	1749	721	107	1.63	4.16	0.50	8.39	21.32	80.50
Costa Rica	3822	1026	112	1.66	9.91	0.29	8.65	57.20	73.90
Dom. Rep.	2453	998	94	1.42	1.77	0.42	8.05	12.53	74.50
Guatemala	1147	554	114	1.19	1.87	0.49	8.23	14.78	77.00
Honduras	1209	393	109	1.35	0.34	0.33	8.05	8.04	70.60
Haiti	662	611	101	1.15	0.08	0.94	7.70	18.01	46.20
Mexico	1859	463	117	1.65	3.59	0.28	9.04	14.91	60.70
Nicaragua	1735	468	125	1.35	0.21	0.28	8.62	13.79	75.90
Panama	2239	744	102	1.85	2.16	0.35	8.60	11.23	69.90
Paraguay	2551	769	104	1.57	4.86	0.40	8.24	11.26	86.30
El Salvador	1389	871	108	1.29	3.02	0.65	8.36	61.99	78.30
Trin. & Tob.	2211	1699	96	1.98	20.45	0.77	9.14	142.26	69.10
Uruguay	10,495	648	107	1.85	13.21	0.07	8.91	19.98	79.10

Notes: The three productivity measures are sourced from the International Agricultural Productivity database (USDA ERS). Labor productivity is measured as the amount of gross agricultural output per 1000 economically active persons in agriculture. Land productivity is the ratio of total gross agricultural output to total agricultural land area (in hectares), where land area is expressed in "rainfed cropland equivalents" (which adjust for differences in land quality based on irrigation status and land type—cropland or pasture). The Total Factor Productivity (TFP) index is the ratio of total agricultural output to total inputs, with base year 1961. Inputs included in TFP calculations are quality-adjusted land, labor, machinery power, livestock capital, synthetic NPK fertilizers, and animal feed, with weights assigned based on factor cost shares. Gross agricultural output and inputs are evaluated at constant 2004–2006 global-average prices and measured in international 2005 dollars. A detailed description of all predictors is provided in Table 1.

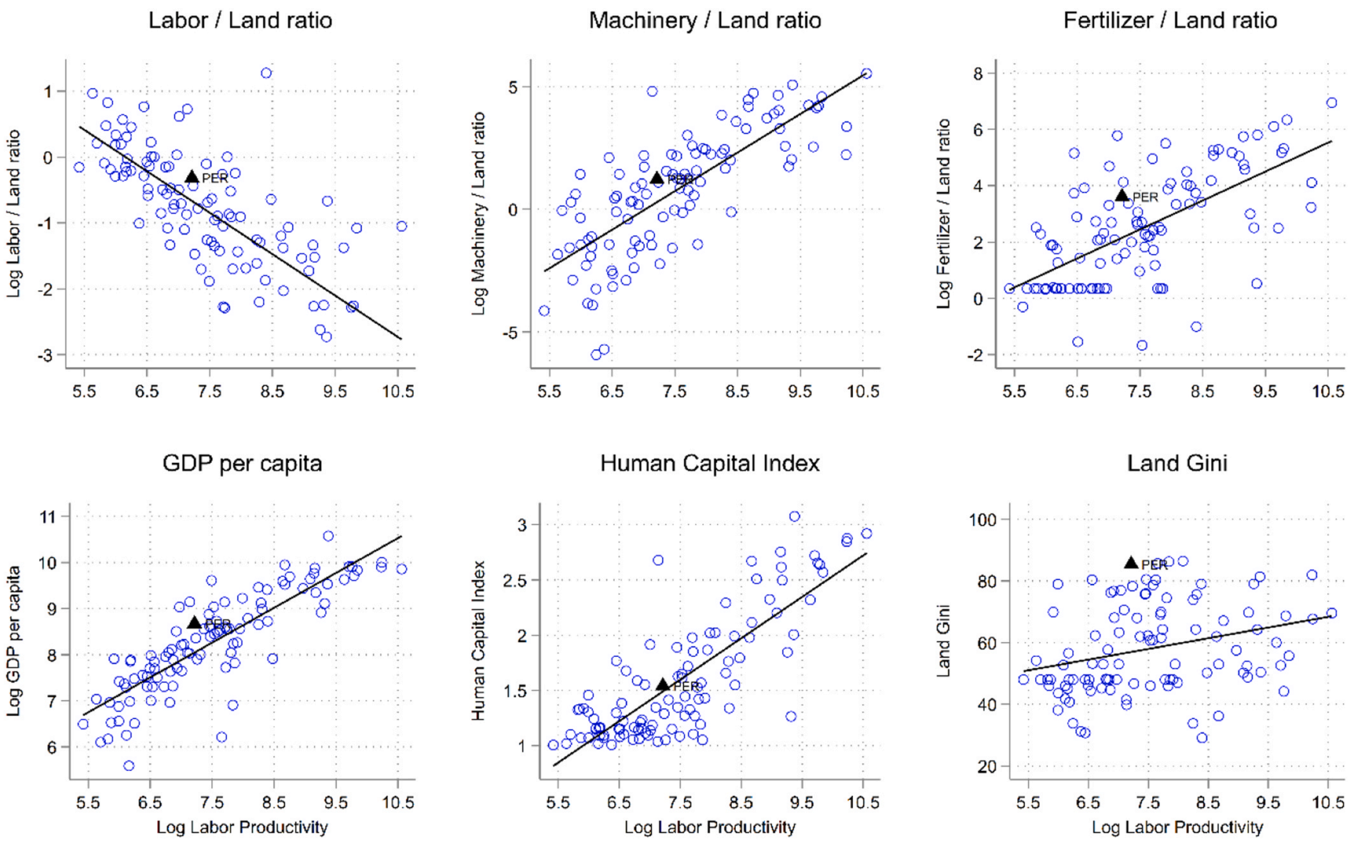

Fig. A.1. Predictors' correlation with labor productivity (1961–1968)

Notes: The figure depicts scatter plots showing the relationship between the average value of each predictor and average labor productivity across a sample of 101 countries over the period 1961–1968 (for detailed descriptions of each predictor, see Table 1). The black line represents the linear prediction between each pair of variables. The correlation between labor productivity and each predictor are as follows: labor-land ratio (correlation = −0.70), machinery-land ratio (correlation = 0.77), fertilizer-land ratio (correlation = 0.64), GDP per capita (correlation = 0.85), human capital (correlation = 0.81), land Gini (correlation = 0.29).

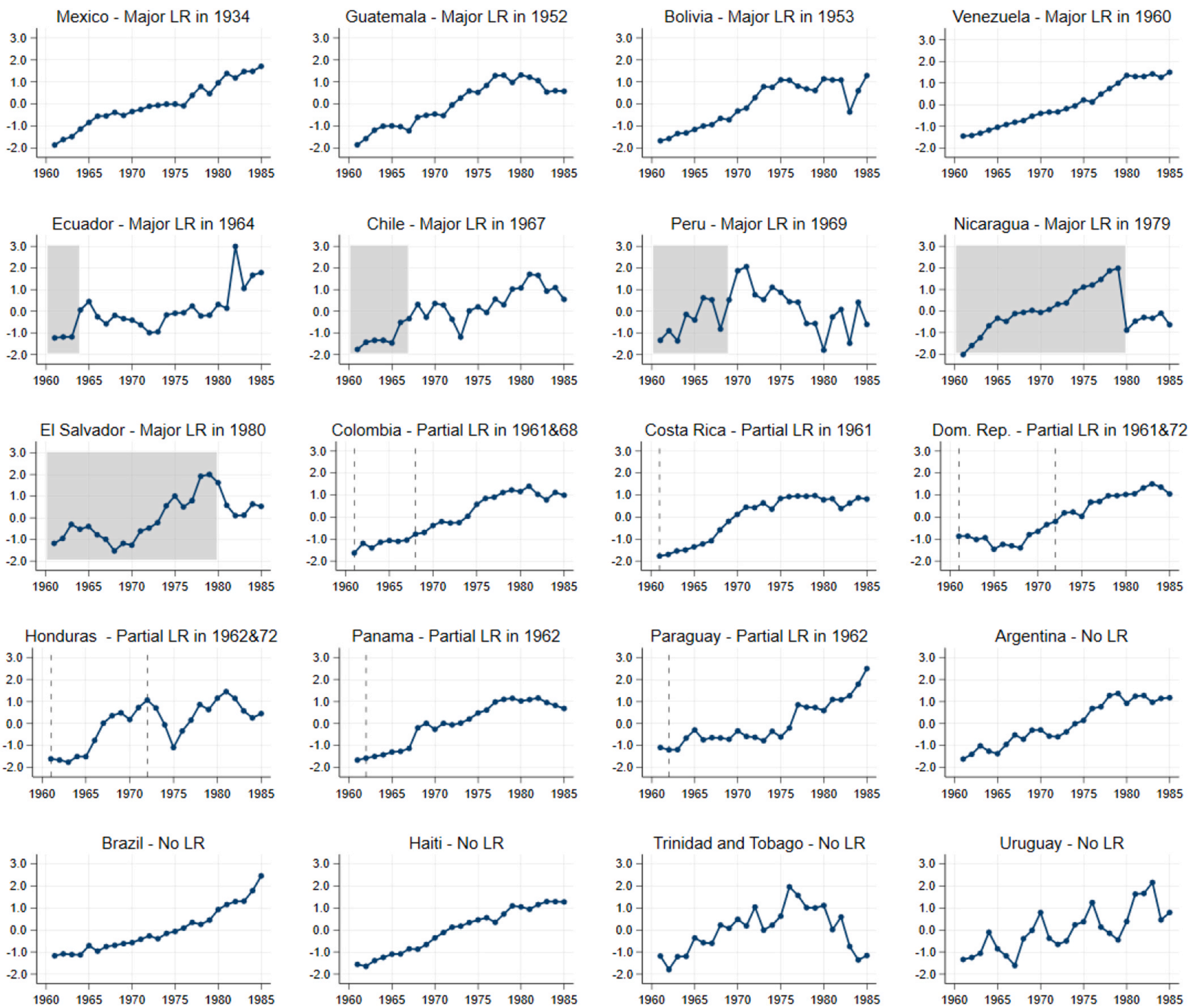

Fig. A.2. Labor Productivity Trends in Latin American Countries (1960–1985)

Notes: Labor productivity is sourced from the International Agricultural Productivity database (USDA ERS) and is measured as the amount of gross agricultural output per 1000 economically active persons in agriculture. Gross agricultural output is evaluated at constant 2004–2006 global-average prices and measured in international 2005 dollars. For comparison purposes, labor productivity trends were standardized to have a mean of zero and a standard deviation of one. The shaded areas indicate the pre-reform period for countries that underwent major land reforms, while the dashed vertical lines indicate the year of land reform enactment for countries that underwent marginal or partial land reforms.

Fig. 3 presents country-level labor productivity trends between 1960 and 1985, categorizing nations into three groups based on the extent of land reform. This categorization emerges from a triangulation of key studies on the subject (Bhattacharya et al., 2019, de Janvry, 1981, Lipton, 2009, Eckstein et al., 1978, and Binswanger et al., 1995). The first group includes nine countries that undertook major land reform projects, which significantly altered land distribution. Four of these (Mexico, Guatemala, Bolivia, and Venezuela) conducted reforms prior to 1961, displaying steady productivity increases in the subsequent decades. The other five (Ecuador, Chile, Peru, Nicaragua, and El Salvador) implemented reforms between 1964 and 1980 and showed rising productivity before the reform, followed by stagnation or decline afterward—most notably in Peru and Nicaragua. In these cases, large-scale land redistribution often involved collective structures and inadequate property rights, suggesting a potentially adverse impact on agricultural productivity growth.

The second group—Colombia, Costa Rica, Dominican Republic, Panama, Paraguay, and Honduras—experienced partial or marginal land reforms, largely in the early 1960s. Their agricultural productivity generally continued to increase steadily, although Honduras briefly declined in the mid-1970s before recovering. Finally, five countries that did not undergo land reform before 1985—Argentina, Brazil, Haiti, Trinidad and Tobago, and Uruguay—generally showed upward productivity trends, albeit with varying degrees of volatility. Argentina, Brazil, and Haiti exhibited consistent growth, while Trinidad and Tobago and Uruguay showed more erratic patterns.

Appendix B. Additional Results

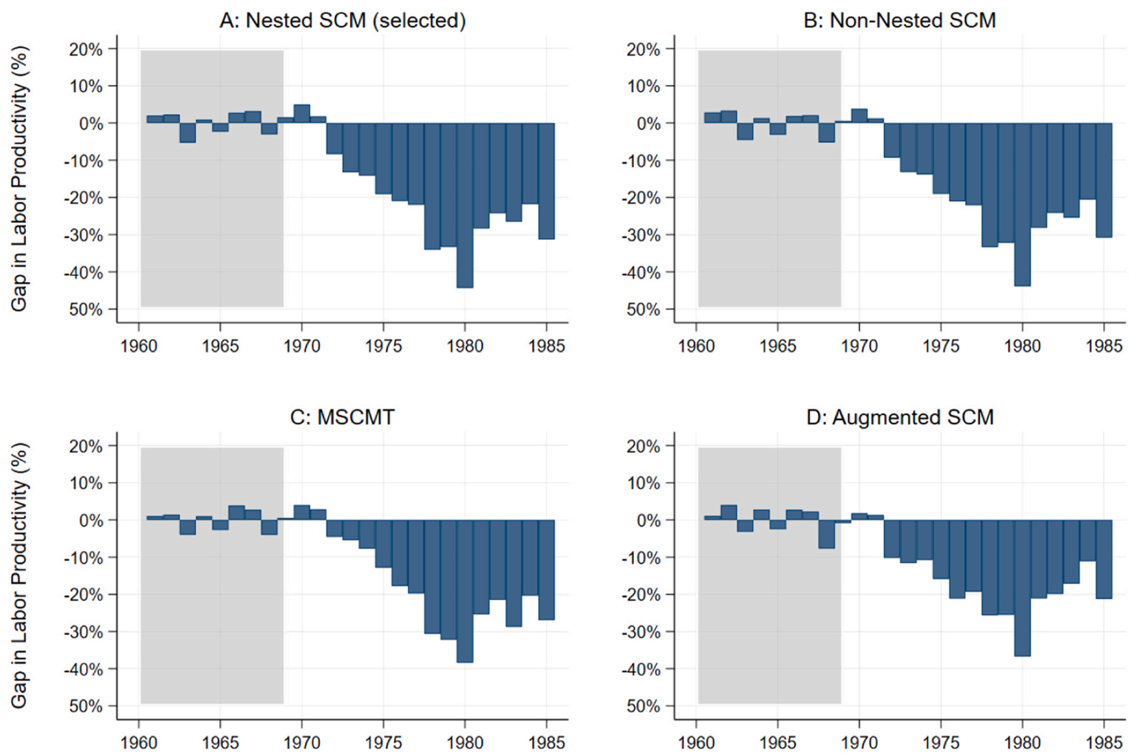

Fig. B.1. The impact of Land Reform on Labor Productivity Alternative Optimization Methods

Notes: Nested and Non-Nested SCM models were estimated in Stata, while MSCMT and Augmented SCM models were estimated in R using the packages *mscmt* and *augsynth*, respectively. Pre-reform / Post-reform RMSPE (%): Nested SCM (2.9 %/22.8 %), Non-Nested SCM (3.2 %/22.4 %), MSCMT (2.9 %/20.2 %), Augmented SCM (3.7 %/17.8 %).

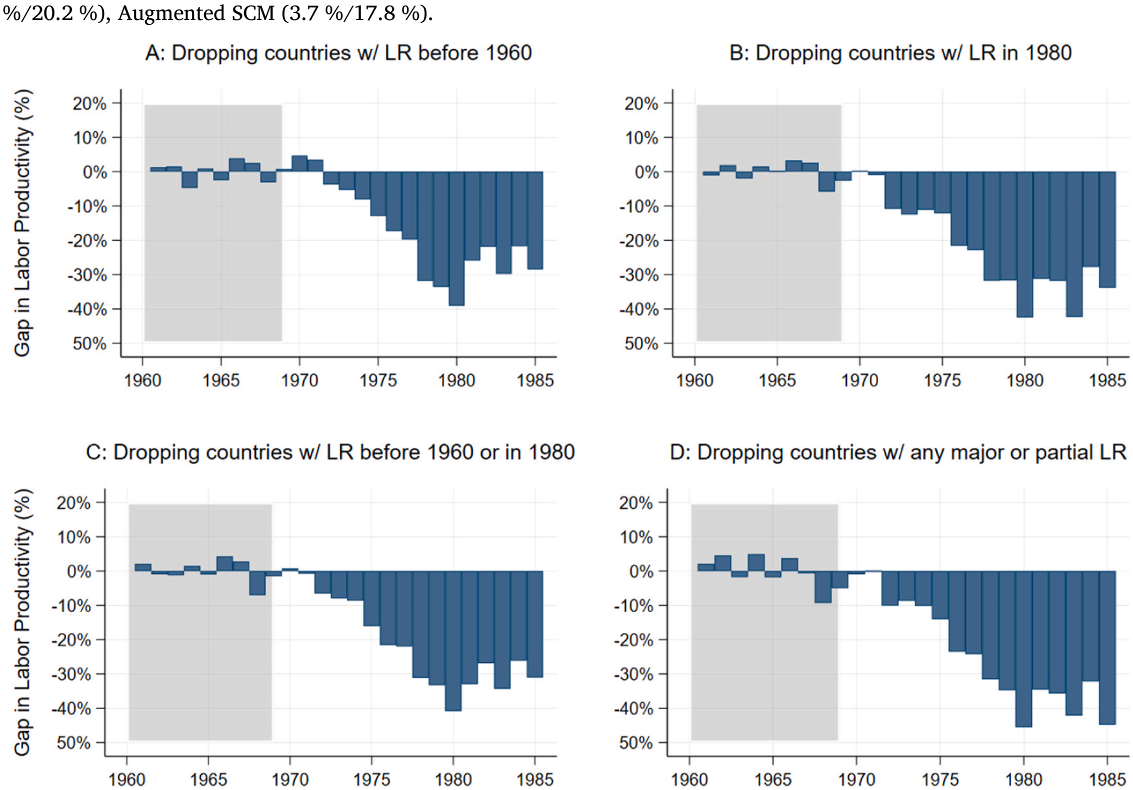

Fig. B.2. The impact of Land Reform on Labor Productivity Donor Pool Excluding Countries that Underwent Land Reform

Notes: Panel A excludes Mexico, Guatemala, and Bolivia from the donor pool. Panel B excludes Nicaragua and El Salvador. Panel C drops the five countries not included in panels A and B. Panel D drops the previous five countries and also Colombia, Costa Rica, Dominican Republic, Honduras, Panama, and Paraguay, which experienced marginal or partial land reforms in the 1960s. Pre-reform / Post-reform RMSPE (%): Panel A (2.7 %/ 19.8 %), Panel B (2.8 %/24.5 %), Panel C (3.3 %/23.1 %), Panel D (4.4 %/26.8 %).

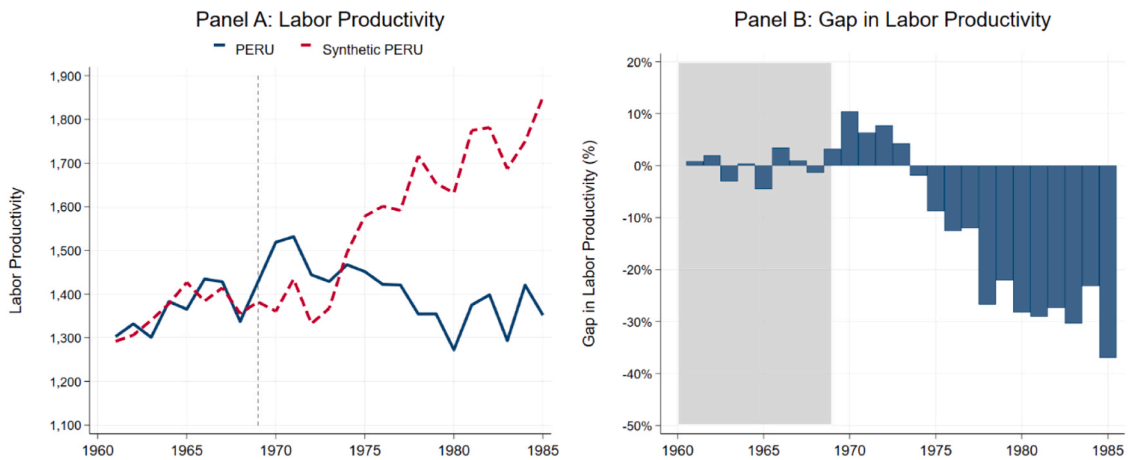

Fig. B.3. The impact of Land Reform on Labor Productivity Expanded Donor Pool including Latin American, Asian, and African Countries

Notes: Donor pool based on a sample of 67 countries from Latin America (16), Sub-Sahara Africa (32), Asia (13), and West Asia and North Africa (6). The weight given to each country in the synthetic version of Peru are the following: Philippines (42 %), Senegal (23 %), Paraguay (17 %), Korea (6 %), Mexico (6 %), and Japan (5 %). Pre-reform RMSPE: 34 (2.5 %). Post-reform RMSPE: 276 (19.6 %).

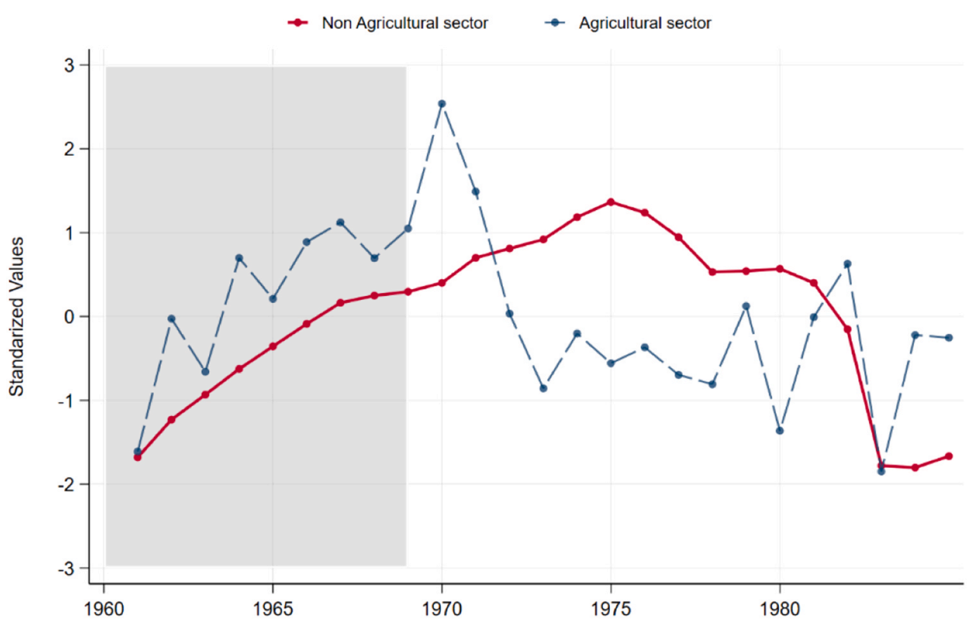

Fig. B.4. Added Value per Worker in the Agricultural and Non-Agricultural sectors

Notes: Sectoral added value is expressed at constant 2015 national prices (in millions) and employment is expressed in thousands of workers engaged in the sector. The measures of added value per worker were standardized to have a mean of zero and a standard deviation of one. The shaded area indicates the pre-reform period (1961–1968). The non-agricultural sector comprises mining, manufacturing, energy, construction, trade services, transport, business services, government services, and personal services. Source: Groningen Growth and Development Centre (GGDC) Sector Database (Timmer et al., 2015).

The figure depicts the trends in added value per worker for the agricultural and non-agricultural sectors, which can be interpreted as measures of sectoral productivity. To ensure the comparability of the two series, we use agricultural added value per worker instead of our preferred measure of land productivity sourced by USDA. However, both series are highly correlated and show a similar pattern over the examined period.

The productivity series of the agricultural and non-agricultural sectors display a low and non-significant association ($r = 0.23, p = 0.2721$). The trends observed shortly after land reform started are substantially opposed, as productivity in the agricultural sector sharply decreased from 1970 to 1975, while that of the non-agricultural sector experienced sustained productivity growth. These divergent patterns are also apparent in the early 1980s when productivity expanded in the agricultural sector and contracted in the rest of the sectors.

Appendix C. Labor and land productivity decomposition

We decompose land and labor productivity growth into the share due to TFP and the share due to using other inputs more intensively per unit of land or labor. The decomposition is based on USDA methodology.[27]

We begin by breaking down the growth in output into the component due to the growth in TFP and the growth in factor inputs. This output growth decomposition can be represented by the following equation.

$$g(Y) = g(TFP) + \sum_{j=1}^{J} S_j g(X_j) \tag{A.1.}$$

Where the function $g(.)$ represents the annual rate of growth in a variable, Y is gross agricultural output, TFP is Total Factor Productivity (Y/X), S_j is the cost share of the jth input, and X_j is amount of input j. The equation above is a cost decomposition of output growth since each $S_j g(X_j)$ term gives the growth in cost from using more of the jth input to increase output, while holding prices fixed.

We can also focus on a particular input, say land or labor, and decompose growth into the component due to expansion in this resource and the yield of this resource:

$$g(Y) = g(X_1) + g\left(\frac{Y}{X_1}\right) \tag{A.2.}$$

Where X_1 refers to a particular input (e.g., land or labor). This decomposition corresponds to extensification (land or labor expansion) and intensification (land or labor yield growth). Using Eqs. (A.1.) and (A.2.) we can further decompose yield growth into the share due to TFP and the share due to using other inputs more intensively per unit of input:

$$g\left(\frac{Y}{X_1}\right) = g(TFP) + \sum_{j=2}^{J} S_j g\left(\frac{X_j}{X_1}\right) \tag{A.3.}$$

Eq. (A.3.) is a decomposition of input yield growth.

Data availability

Data will be made available on request.

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