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Winners and losers from agrarian reform: Evidence from Danish land inequality 1682–1895☆

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ABSTRACT

Pro-market and pro-farmer agrarian reforms enacted in eighteenth century Denmark laid the basis for rural development but we demonstrate that they also resulted in increased inequality. We investigate this using a novel parish-level database spanning more than two centuries. We identify the impact of land quality on inequality following the reforms by instrumenting with soil type and find increases in areas with more productive land. We propose and find evidence for a mechanism whereby agrarian reforms allowed areas with better soil quality to realize greater productivity gains. This in turn led to greater population increases, and a larger share of smallholders and landless laborers. Finally, we demonstrate the impact on the winners and losers: more unequal areas witnessed increases in top incomes, but greater emigration of the rural poor, to the United States in particular. Thus, the losers were able to vote with their feet, in stark contrast to those who might lose from similar reforms in developing countries today.

1. Introduction

What determines patterns of land inequality following agrarian reform, and what is the impact on equity and efficiency? Although such questions are at the heart of development economics as a field, it is difficult to generalize conclusions given the vast variation in institutional, geographic and other factors in the various settings where agrarian reforms have been enacted. We consider a seminal predecessor of pro-efficiency land reforms, the Danish agrarian reforms from the late 1700s, when common lands and serfdom were abolished, and new agricultural methods were introduced (see also Lampe and Sharp, 2019b; Dall Schmidt et al., 2018; Boberg-Fazlic et al., 2020; Jensen et al., 2018). We first look at the effect on land inequality, and then examine the impact of this inequality on 'winners', those who came to own large and medium-sized consolidated farms, and 'losers', those who came to hold little or no land.

There are at least two reasons for the relevance of the Danish case. First, Denmark possesses extremely detailed data for this period, and moreover data which allows us to study the impact of agrarian reform a century after its implementation. These have not so far been exploited. Second, Denmark is today famously equal and rich, and moreover has been held up by previous generations of development economists as a model for agriculture-based development. Thus, the Danish development economist, Esther Boserup, explicitly took inspiration from the history of her homeland (see for example Boserup, 2014), and the Food and Agriculture Organization of the United Nations published a study on exactly this issue (Skrubbeltrang, 1953). Moreover, important

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historical agrarian reforms, such as the Stolypin land reform of 1906–17 in Russia, were based on the Danish precedent (Korchmina and Sharp, 2021). Finally, what might in some ways be described as the end result of the Danish reforms, the successful agricultural cooperative movement which emerged in the 1880s, has also inspired countless development policies both contemporaneously, and more recently (see the discussion in Lampe and Sharp, 2019a).

Agrarian reforms need to balance equity in access to land with efficiency in the size of productive units that can take advantage of markets and technologies, as we will discuss below. Despite its current reputation for equity, in the 1700s Denmark chose to prioritize efficiency. Successful agrarian reform - not unlike the recent decollectivization of agriculture in transition economies (Zhao, 2020; Ravallion and van de Valle, 2008; Rozelle and Swinnen, 2004) – has often been considered to be central to the subsequent increases in agricultural productivity and a key precondition for economic modernization and industrialization. Such liberalizing ‘agricultural revolutions’ rely on the freedom of post-reform households to adopt new crops, crop rotations and other forms of agricultural improvements to increase agricultural productivity and production. An interesting case is presented by Montero (2022), who considers reforms undertaken by the military junta in El Salvador, where estates larger than 500 hectares were redistributed from private owners to cooperatives, keeping the farm size constant, resulting in more equitable rural economies based on staple crops and higher incomes. In Denmark, the rise of a peasant farmer middle class thanks to the reforms created a particular version of national historiography that attributes large parts of Danish economic progress and social cohesion to its reforms (Kjærgaard, 1980, 1994). Economically, for example, Dall Schmidt et al. (2018) found that the introduction of clover, a key agricultural innovation from around the time of the reforms, accounted for about eight percent of the growth in the population of market towns between 1672 and 1901. On the other hand, such land reforms and dissolutions of commons, now and then, have rightly or wrongly been accused of increasing economic pressure on the land-poor and landless (cf. Ravallion and van de Valle, 2008). Indeed, in the Danish case Kjærgaard (1994, p. 251) has emphasized that the praise heaped on the agrarian reforms by the farmer-oriented historiography meant that “no attention has been paid to freehold tenure and enclosure as mechanisms for economical expropriation. The damage this inflicted upon the lower rural class has not been taken into consideration”. In fact, with the extension of the franchise, the losers were to play an increasing role in the early twentieth century, eventually sparking a series of new reforms (see for example Aaskoven, 2021). In the present work, therefore, we not only provide the first quantitative long-term assessment of increasing efficiency *and* increasing inequality, but also document the effect of the latter on the winners and losers.

Using unique data covering two centuries of land inequality, we demonstrate that the pro-efficiency land reforms caused inequality to increase more in areas with better quality land. As soil quality is potentially endogenous to land management, we identify this effect using a novel instrument based on the way Danish soil was formed during the last ice age, and present evidence for a mechanism through differential rates of population growth. We then turn to the impact of this inequality. By prioritizing efficiency over equity, and accepting greater inequality of landholdings (but limiting this at the extremes of the distribution), Denmark created a politically and economically sustainable rural middle class. From the 1880s this rural middle class became instrumental for the rapid industrialization of the countryside, largely through cooperatively owned butter factories (see Lampe and Sharp, 2019a; Boberg-Fazlic et al., 2020). The fact that the reforms, which began in 1784, took place alongside the political turbulence following the spread of liberal and enlightened thought, as well as the American and French revolutions, was of course not coincidental (see Horstbøll and Østergaard, 1990), and we note parallels with reforms pushed through to prevent the spread of communism during the Cold War in countries such as Korea, Taiwan, the Philippines, Japan (see for example You, 2014; Kapstein, 2017), and Italy (Caprettini et al., 2021).

However, agrarian reform which prioritizes efficiency (in terms of viable landholdings for agriculture) may result in the creation of classes of landowners and the landless. For the former, we find evidence from income taxes that top incomes increased following the reforms in areas of greatest land inequality. For the losers, meanwhile, we find that many chose to emigrate, particularly to the United States. Thus, although our findings are to some extent specific to the Danish case, they can nevertheless be argued to have important policy lessons. The success of agrarian reform depends to a large part on economic and political sustainability. The reforms chose the efficiency route and created an economically and politically stable class of medium-sized landowners which was to dominate Danish politics and form the basis of national identity for decades. Although the counterfactual is impossible to test, one might argue that this political sustainability was at least enhanced by the fact that the losers, i.e. those who ended up holding little or no land, had a quite obvious outside option: emigration. Thus, in a similar way to how Boserup famously argued that Danish development through agriculture, which was largely dependent on export markets in the UK, might be impossible to replicate for the poor countries of today in a world of agricultural protectionism, we might add that agrarian reforms seeking efficiency over equity today might also be hampered by the rich world’s immigration restrictions.

Fig. 1 presents a simple way to envisage the mechanisms we describe in more detail below. Soil quality, as determined during the last ice age, in turn determined the distribution of agricultural lands following the agrarian reforms. This was to a large part due to institutional reasons: medium-sized holdings (and the demesnes of the larger traditional landed estates) were more-or-less untouched. As agricultural productivity began to reflect soil quality (for a given technology) to a greater extent following the reforms, this stimulated a Malthusian expansion of population in the most productive areas, which in turn gave rise to a larger proportion of the population with little or no land, and land inequality increased. The losers from this process turned to emigration, once this became economically viable due to falling transportation costs and increasing incomes, towards the end of the nineteenth century. On the other hand, population growth also stimulated innovation, reinforcing the productivity impacts of the reforms. Consistent with this, we find evidence that the incomes of top earners increased.[1]

Thus, the remainder of this paper proceeds as follows. The next section presents a survey of the relevant literature, and Section 3 discusses the historical background to the Danish case. Section 4 presents our data and Section 5 presents our methodology and results on the determinants of inequality. Section 6 explores the potential mechanisms, Section 7 presents evidence on the effects of inequality and Section 8 concludes.

2. Literature survey

Regarding the origins of land inequality, the most famous hypothesis was postulated by Engerman and Sokoloff (1997) who argue that factor endowments of soil and climate as well as the presence of native populations predisposed colonies towards paths of development associated with different degrees of inequality in terms of wealth, human capital and political power. Thus, for example, the type of soil determines which crops are grown, and areas with soil suited for crops best cultivated on large-scale plantations developed greater inequality, which in turn hindered economic growth. Easterly (2007) provides

[1] Here, top earners are people above the income threshold paying income taxes, roughly 15% of all households in 1870.

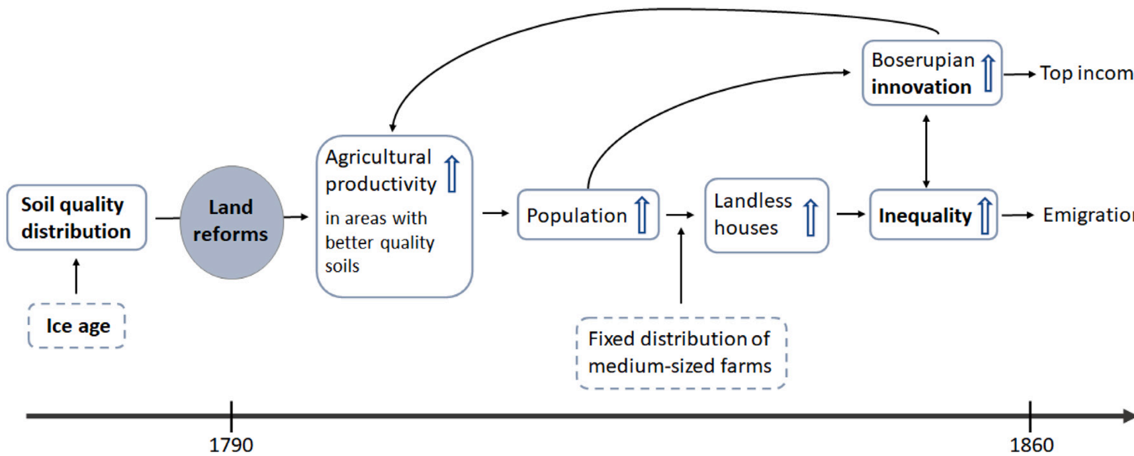


Fig. 1. Flow chart of the proposed relations and mechanisms.

confirming evidence, although Nunn (2014) discusses how work examining this hypothesis has found rather opposing results.[2] In contrast to Engerman and Sokoloff, we zoom into the land-quality-inequality nexus by focusing on the inequality consequences of better soils in an otherwise relatively small and homogeneous country, the Kingdom of Denmark. We trace an emerging pattern of higher land inequality in areas with better quality soil that only emerged after liberal land reforms, as these enabled new opportunities for realizing productivity gains. Population responded through increased fertility (in line with basic Malthusian predictions). Under an institutional framework that aimed to maintain family farms for mainly political reasons, this meant that while reform freed agriculture from the constraints of communal cultivation and manorial duties, it also led to increased numbers of people with little or no access to land.

In contrast, the current development literature is mainly concerned with pro-poor land reforms, primarily aiming at poverty reduction and often introduced by left-wing governments (Albertus et al., 2020; Bhattacharya et al., 2019; Besley et al., 2016; de Janvry et al., 2014; Dower and Pfutze, 2019; Keswell and Carter, 2014). While generally focusing on increased equity, the socioeconomic outcomes of these pro-poor reforms are much debated in the literature and seem to be highly dependent on the political economy surrounding each individual case. Another strand of the literature is concerned with the effects of changing communal cultivation forms into more household based forms, for example, in recent transitions from socialist collective ownership (Chen and Lan, 2020; Zhao, 2020; Ravallion and van de Valle, 2008), in the case of Mexico's ejidos (Valsecchi, 2014) and of the Stolypin reforms in the Russian Empire that gave individual land titles to rural households tied to the village community even after the abolition of serfdom (Chernina et al., 2014). According to Lipton (2009), decollectivization has been pro-poor in for example the case of China, i.e., based on transfers of property rights to labor-intensive, egalitarian peasant farms, under the household responsibility system (Lin, 1991, 1992; Gong, 2018), but not if it has been as in Russia, which witnessed privatization of large State conglomerates, which remain inefficient. The Eastern European reforms were more successful in enhancing the operational efficiency of private markets,[3] from which the poor also gained, although less than the rich, whereas the Latin American and African experiences (where collectivization was never as extreme as in the Soviet Union) lay somewhere in between. More similar to the Danish case, however, are pro-market and pro-household reforms, which have generally been credited with increasing the economic agency of peasants, often leading to increased agricultural efficiency through modernization and investments, although the timing of evaluation seems to matter (Helfand et al., 2019). Such reforms have been shown to lead to politically and economically counterintuitive results, such as the rise of more conservative voting behavior (de Janvry et al., 2014), and the use of more affordable draft-animals instead of the former collective's tractors (Chen and Lan, 2020). More comparably to our findings, others have documented increases in landless households, for better or worse (Ravallion and van de Valle, 2008), and the facilitation of rural exodus (Chernina et al., 2014; Valsecchi, 2014). Existing studies also show that outcomes are often heterogeneous and depend, for example, on geographical conditions, market access and labor market alternatives in the wake of the reforms, or on the prior degree of access to land.

Within economic history, the introduction of secure and consolidated private property rights to land is considered central to the process of agrarian reform and economic modernization more generally, and mirrors the debate in development economics (Acemoglu and Robinson, 2012; Albertus, 2015; Binswanger-Mkhize et al., 2009; Jones, 2018). A significant fraction of this literature has focused on the English parliamentary enclosures. In traditional open-field agriculture, as in both Denmark and England, villagers cultivated land distributed in scattered strips around the village. The consolidation of these landholdings through enclosure served to reduce the time it took moving from one strip to another, and thus had the potential to facilitate new agricultural techniques, crop specialization and in general to increase investment in the land (Overton, 1996a,b; Brakensiek, 1991, 1994). Such enclosures often went hand in hand with the dissolution of commons, for example for grazing cattle, which groups with less direct land rights were more dependent on (Allen, 1992; Brakensiek, 1991, 1994; Neeson, 1993; Overton, 1996a,b; Whittle, 1998, 2000; Campbell, 2005; Kopsidis, 2006; Olsson and Svensson, 2010). Otherwise, the exact nature of these reforms differed greatly between different countries and regions: for the English case, see Allen (1992); for the Prussian case, see Federico (2005), Kopsidis (2006) and Fertig (2007); for the Russian case, see Chernina et al. (2014) and Dower and Markevich (2019); and for the Irish case, see Foley-Fisher and McLaughlin (2016). Thus, the historical literature varies widely in its assessment of the productivity effect of agricultural reforms, reflecting how and under which institutional conditions (e.g., the degree of forced labor for the manorial economy) villagers cultivated the open fields (and managed the commons) and the institutional arrangements of the reform process,

[2] See also Dell (2010), Acemoglu et al. (2008) and Nunn (2008), with the most recent work, by Fujiwara et al. (2021) again providing support in the context of Brazil, where they identify a causal relationship between historical slavery and present-day inequality.

[3] For the East German experience see Mathijs and Swinnen (2001), who find smaller farms to be more efficient than 'large-scale successor organizations of collective and state farms' - but that the efficiency gap declined during the transition.

i.e., who obtained which property rights under which conditions (see, e.g. McCloskey, 1975; Allen, 1992; Brakensiek, 1991, 1994; Overton, 1996a,b; Kopsidis, 2006; Fertig, 2007).

Finally, the present work also links to the literature on geography and economic outcomes (see for example Fernihough and O'Rourke, 2020) as well as the impact of inequality on various measures. Thus, for example, Vollrath (2007) finds a negative relationship between land inequality (measured by the Gini coefficient of farm sizes) and productivity (output per hectare) across countries, although other studies (Bhalla, 1988; Bhalla and Roy, 1988) demonstrate that this disappears when controlling for soil quality. Galor et al. (2009) find a negative relation between land inequality and investment in public schooling, although Vollrath (2013) finds that in the case of the United States this is only present in the north and not the south. Cinnirella and Hornung (2016) find a negative impact of landownership concentration on school enrollment in Prussia. Other studies have found links between land inequality on for example redistributive policies (Alesina and Rodrik, 1994; Persson and Tabellini, 1994, 1996); on schooling and human capital (Deininger and Squire, 1998; Erickson and Vollrath, 2004; Easterly, 2007; Galor et al., 2009; Kourtellos et al., 2013; Gray and Clark, 2014; Cinnirella and Hornung, 2016; Goñi, 2021; Oto-Peralías and Romero-Ávila, 2016; Ashraf et al., 2017; Baten and Hippe, 2018); on agricultural efficiency (Vollrath, 2007; Martinelli, 2014); on financial development (Vollrath and Erickson, 2007); and finally, for population and economic growth (Vollrath, 2012). Recently, Bartels et al. (2020) and Huning and Wahl (2021) have taken up the issue of inheritance rules for the determination of land inequality, and, for the German case, use this to determine their impact on a variety of outcomes, also in the long run, including the transition to industry and migration.

Our work complements all the above, and exploits the Danish case to provide lessons on what determines land inequality, and in turn the positive and negative impact of this through winners and losers from the process, in both the short and medium to long run.

3. Agrarian reforms in Denmark, 1784 - ca. 1810

As with much else in economic history, our story starts with the Black Death.[4] As a consequence of a fall in population after the 1340s and unfortunate changes in the taxation of free peasants around the same time, ca. 60,000 subordinate farms emerged in the fourteenth and fifteenth centuries, and the free peasantry more or less disappeared (Arup, 1933; Porskrog Rasmussen, 2003, p. 8). These farms remained roughly constant until the beginning of our period. Thus, before the land reforms, about 98–99 percent of land was owned by estate owners, among them the crown, the church, schools and universities, as well as private owners from the nobility and (from 1660) the bourgeoisie. Just 1–2 percent of the land was in the hands of freeholders. Estate owners directly controlled their main farms (the demesnes) which made up 8.5 percent of all land,[5] and the rest of the land was cultivated by middle-sized farms and smallholders, who held land-use rights in the traditional form and paid rents in money and in kind as well as labor services to the estates who held the 'direct ownership' rights to the land. The inefficiency in the use of much of the land is well-documented, and the land use studies by Frandsen (1977, 1983) have found that in 1662, admittedly a time of crisis, only twenty to thirty percent of the land classified as arable in 1688 was cultivated (cf. Skrubbeltrang, 1978, pp. 276–7).

The unification of property rights was one major aim of the period of reform from the late eighteenth century. Thus, by 1834 50 percent of the land was held by farmers and smallholders in freehold property (*selveje*) or inheritable tenancy (*arvefæste*), while still almost 10 percent belonged to the traditional estates in the form of demesnes, and 40 percent was still under old-school property-rights as 'tenancy for life' (*fæste*), whose legal definition moved more or less continuously in the direction of the farmers, and to a lesser degree, smallholders (Jensen, 1945, pp. 277, 366–367). During these reforms, arable land began to be used in more intensive crop rotations and some of the former pastureland and woods were reconverted into arable land, involving substantial investments in work and money by peasants, to make way for more intensive techniques and more and more efficiently used livestock (Dombernowsky, 1988, Kjærgaard, 1994, pp. 25–27 and ch. 3, Skrubbeltrang, 1978, pp. 98–100, 242–4, 406-7, Lampe and Sharp, 2019a). Population, which had remained a little over half a million since at least the 1600s, began to grow at much higher (and steady) rates above 1 percent per year from the 1780s throughout the nineteenth century, so that Denmark had 2 million inhabitants by 1880 and 2.75 million in 1911 (Johansen, 2002, pp. 125,173, Skrubbeltrang, 1978, pp. 391–93, Kjærgaard, 1994, p. 13, and Lassen, 1965). We attribute the break in the pattern of population and the transition to higher growth rates to the land reforms and enclosures that took place between 1784 and the first decade of the nineteenth century, although as we will show, this growth differed markedly across the country.

The history of the reforms is rather convoluted and in practice took many decades to complete, with a defining moment being the arrival of a new class of 'enlightened landowners' and the introduction of the Holstein System of agriculture to Denmark from the late 1760s to the end of the eighteenth century.[6] The central piece of enlightened absolutist reform, at least as far as our story is concerned, was the agrarian reforms that were gradually enacted between 1784 and 1807. Apart from the end of adscription in 1788, most of the measures aimed at dismantling the communal cultivating system with its open fields and grazing rights shared between farmers and cotters of one or several villages.[7] The Danish land reforms basically cemented the existing farm structure at the expense of the rights (but not the main farmlands) of estate owners and the social and economic position of smallholders and landless agricultural laborers. The main beneficiaries were the tenant-owners of the 60,000 medium sized family farms who managed to establish themselves as a stable rural middle class. By 1810, more than 40,000 of these had been converted to 'full' freehold property (Dombernowsky, 1988, p. 359).

This stability in the number of middle-sized farms was not coincidental, but rather a consequence of how the reforms gave preferential treatment to the peasants operating the middle-sized farms at the time of reform (Henriksen, 2003), which has been interpreted as the manifestation of the political will of the absolutist reformers in fomenting a bond between the peasant population and the central administration to circumvent the local power of the nobility (Kjærgaard, 1994; Jensen, 1945, pp. 441–450). Legally, this pro-farmer political equilibrium expressed itself in at least three dimensions: First, already in 1769 and 1786, a minimum size for a farm to provide for a family was defined by law. Second, it was generally prohibited to sell land in a way that farms would fall below this threshold or to dissolve farms completely. Third, inheritance decrees in 1837 and the 1845 inheritance law made it permissible to treat offspring unequally for the purpose of keeping farms together. These institutional arrangements effectively limited access to land for smallholders.

The end result was that the reforms had by the early nineteenth century established modern property rights, allowed for individual cultivation (e.g. of clover) and the use of more capital-intensive technologies (e.g. animal husbandry, which allowed for higher yields by providing additional fertilizer in a world of organic farming). This made

[4] This part draws on the material used for chapter 3 in Lampe and Sharp (2019a).

[5] Own calculation, in terms of *hartkorn* (see below).

[6] For a detailed survey see Kjærgaard (1994) and Lampe and Sharp (2019a).

[7] See Skrubbeltrang (1978, pp. 135–40, 276–77) for an overview of the old system.

it possible to overcome prior institutional (common cultivation of open fields, insecure tenancy leading to underinvestment) and technological constraints on land use, and hence enabled higher agricultural yields and, in consequence, population growth. While the land–labor ratio deteriorated with the growth of population and labor force especially from the 1780s, the size distribution of farms remained rather constant over the land reforms and a rural proletariat of smallholders (cotters, see Møller, 2016), landless workers and servants grew alongside the more and more established class of tenants and, increasingly, owners of middle sized farms, who could rely on the rural lower classes for more intensive agricultural production (cf. Kjærgaard, 1994, ch. 6). By this, not only a link between better soils and higher agricultural productivity growth was established, but also one between land quality and farm size inequality - a classical efficiency-equity trade-off.

4. Data

We make use of the Danish land registers which give extremely detailed information on the number and sizes of farms per parish. A little historical background is warranted here to help understand the data we use to calculate our parish-level inequality measure. In the wake of defeat by Sweden and the loss of the eastern provinces of the kingdom (Scania), absolute monarchy was introduced to Denmark in 1660. This was followed by the creation of a nationally uniform tax system that introduced as a main source of revenue a tax on the productive capacity of agricultural land in order to consolidate government finances (cf. Horstbøll and Østergaard, 1990, p. 160). The basic idea of the new tax was to establish a land register, assess the productive capacity of the land in a unified system and tax each unit equally. The *tønde hartkorn* (literally: barrel of hard grain, denoted 'HK' in the following) a measure of relative productive capacity, not of actual production, became the basis upon which for example tithes were levied (Skrubbeltrang, 1978, pp. 104–6). In 1681 a land survey was undertaken in all parts of the kingdom. The categorization of land into categories was done publicly, and all types of productive assets (including for example mills) were reduced to HK equivalents (see Skrubbeltrang, 1978, pp. 107–112). A new survey of productive capacity/HK was taken in 1844 and conversion tables are provided in the published statistics (Commissionen for det statistiske Tabelværk, 1844), revealing that the variation across the country remained relatively unaltered, reflecting that this was a subjective measure of potential rather than actual production, and indeed both measures correlate highly with modern land suitability.

The land distribution statistics report the number of farms in different size/HK categories and the corresponding total number of HK.[8] We thus know the number of farms in each parish as well as their distribution in terms of productive capacity. We digitize this data for the years 1682, 1834, 1850, 1860, 1873, 1885 and 1895. The data for the year 1682 is digitized from Pedersen (1928)[9] and for the year 1834 from Commissionen for det statistiske Tabelværk i Danmark (1837). The remaining years are digitized from Statistiske Bureau (1852, 1864a, 1877, 1888, 1896). This gives a panel of farm value distribution in Denmark over a very long time period, covering the extensive land reforms in the late 1700s and early 1800s. Fig. 2 shows the distribution of total HK by area for the year 1682 in the left panel.

We combine this data with animal counts from agricultural censuses for the years 1837 and 1861 (Commissionen for det statistiske Tabelværk, 1842; Statistiske Bureau, 1864b). Here we use the number of cows and the number of pigs per parish. The agricultural censuses also provide the amount of seed sown in the parish for, among other smaller crops, barley, wheat, rye, and oats (Commissionen for det statistiske Tabelværk, 1842; Statistiske Bureau, 1865). We further combine our dataset with population figures on the parish level from the Danish population censuses for the years 1769, 1787, 1801, 1834, 1850, 1860, 1870, 1880 and 1890 (Danish National Archives, 1787, 1801, 1834, 1850; Statistiske Bureau, 1911). We thus do not have population in 1682, the year of our earliest land distribution measure, as the first census was conducted in 1769. However, 1769 is still early enough for us to be able to investigate population before and after the land reforms.

In order to measure the topographical characteristics of the land we use information on soil types from the *Surface Geology Map of Denmark* (Pedersen et al., 2011/2019) which gives a classification of glacial and postglacial sediment types. This means that soil is classified at one meter depth, i.e. below the impact area of the plough and other forms of cultivation. The *Surface Geology Map of Denmark* is based on a digitized version of the 1989 Danish Geological Survey, supplemented with categorization of drilling samples from the GEUS (Jupiter) database and other information in missing areas. It is extremely detailed, such that we have a lot of variation in the soil types even at the parish level. 11 different quaternary sediment types are identified – we use the category 'boulder clay'[10] and calculate the share of the parish classified into this category, as this type of soil seems to have been especially suited for growing barley (Frandsen, 1988). Fig. 2 shows the distribution of boulder clay (as a share of parish area) in the right panel.

In addition, we calculate several geographical variables on the parish level. These include parish area, distance to Copenhagen, distance to the coast as well as the longitude and the latitude of the parish centroid. Here, we use a shapefile of historical parish borders available from the Digital atlas over Denmark's historical administrative geography (*Digitalt atlas over Danmarks historisk-administrative geografi*, downloadable at: digdag.dk).

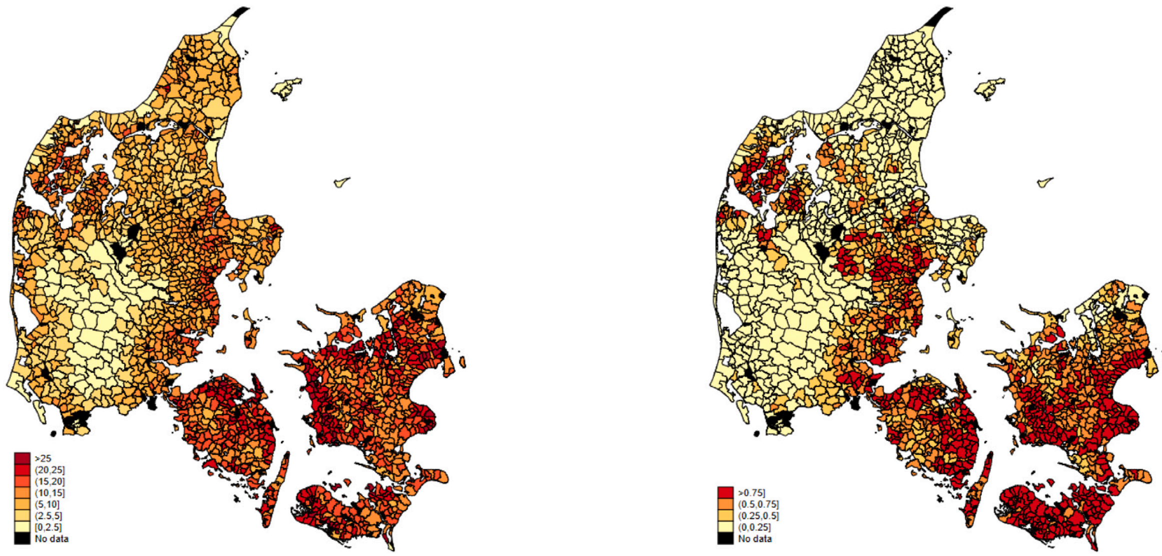
Our data on land inequality in Denmark cover a period of more than 200 years. Naturally, changes in the administrative units occurred, where only changes in parish borders are relevant for us as all our data is on the parish level. We therefore use the parish borders of 1682 and aggregate parishes in subsequent years to the original unit whenever parishes were split or aggregate parishes in the earlier years if they were consolidated later on. We drop the island of Bornholm, as it is not included in the reports in all years. We also drop the area of Southern Jutland which was taken by Prussia during the Second Schleswig war of 1864, as this area is not reported consistently over the whole period for obvious reasons. Additionally, market towns usually consisted of (at least) one parish for the town and one parish for the countryside. Our analysis only includes the countryside where the measure of HK is applied to the land belonging to farms. Sometimes, however, market town and countryside parishes are reported together in some years and not in others. In these cases, we drop the countryside parish of the market town in all years. In the end, we have data on 1605 consistently reported parishes with stable borders across all years.

Finally, a brief explanation is needed to understand the nature of the measure of land inequality we calculate below. It is necessary to differentiate between ownership and 'operational unit inequality', since many of the units we consider were not owners, but were for example tenant farmers. Thus, what we are looking at is not really ownership or wealth inequality. Rather, it is more like income inequality because we are not observing who actually owns the land, but who had access to its productive potential: operational land inequality. Nevertheless, we will refer to this as land inequality below.

[8] See Table A.2 in the Appendix for the classification schemes in the different years.

[9] Note that the title of the publication states 1688, but the data was collected in 1682. We therefore refer to this data as 1682.

[10] In the map this category is called 'Till, clayey and fine-sandy' soil, we refer to it as 'boulder clay' translated from the Danish classification 'moræneler'.



(a) Total HK (b) Boulder clay

Fig. 2. Map of total HK by parish area (1682) and share of parish area classified as boulder clay.

5. Determining inequality

5.1. Methodology

We measure land inequality with the Theil index, as this inequality measure exhibits several analytically desirable properties. First, it satisfies the strong principle of transfers, meaning that a redistribution from one individual to a poorer one will lead to a decline in the Theil index proportional to the absolute distances between the individuals' incomes. This is especially important in our context, as our main results concerns the changes in the Theil index. Second, the Theil index ranks distributions unambiguously. Thus, two places with identical Theil indices will also have identical income distributions.[11] This is not the case with the much more popular Gini index, for example, where crossing Lorenz curves leading to identical Gini indices are a possibility.[12] See also Cowell (2011).

The Theil index T_p is calculated as follows:

$$T_p = \frac{1}{N_p} \times \sum_{i=1}^{I} \left[N_{ip} \times \frac{x_{ip}}{\mu_p} \times ln\left(\frac{x_{ip}}{\mu_p}\right)\right] \quad (1)$$

for parish p and size category of farms $i = \{1, \ldots, I\}$. N_p is the total number of farms in parish p, N_{ip} is the number of farms in size category i in parish p, x_{ip} is the average number of HK in size category i (i.e. total HK in category i divided by number of farms in category i), and μ_p is the total average HK in parish p (i.e. total parish HK divided by total number of farms). If all farms are of equal size, i.e. everyone owns the same amount, the Theil index is equal to zero. Maximum inequality, i.e. if all the land belongs to one farm and other houses in the parish have zero land, is given by $\ln(N_p)$. Fig. 3 shows the Theil index and the Gini coefficient for the whole of Denmark for the years 1682–1895. We see a pronounced increase in inequality over the whole period, with the largest increase over the period 1682 to 1850. In 1682, the Gini coefficient is 0.32, which roughly corresponds to (income) inequality levels in Germany or France and is only slightly higher than Denmark today. By 1850, however, the Gini coefficient increased to 0.67,[13] which is higher than for example Brazil, the most unequal country in Latin America today, at 0.53, and even South Africa — currently the country with the highest measured Gini coefficient at 0.63.[14] Interestingly, the aforementioned reforms in Korea, Taiwan and the Philippines actually reduced inequality, to the most extreme extent in Korea, where the Gini coefficient fell from 0.73 just following the Second World War to around 0.39 by the 1960s (You, 2014).[15]

Fig. 4 shows the distribution of land inequality, measured by the Theil index, in Denmark for the years 1682 and 1834, i.e. before and after the land reforms. A clear pattern of increasing inequality emerges, especially pronounced on Zealand and possibly also Funen. We therefore also include regional fixed effects in all regressions. Maps for the later years can be found in Fig. A.1 in the Appendix. We also note a striking resemblance of the pattern in 1834 with the distribution of HK shown in Fig. 2a.

Our aim is to estimate the effect of productive capacity on inequality. The detailed information we have on productive capacity, in terms of HK, however, may be endogenous to land management. We therefore implement an instrumental variables strategy, where we instrument the productive capacity with the share of parish area covered with boulder clay. To understand the distribution of soil qualities around Denmark,

[11] The Theil index also has the advantage of being decomposable into different elements contributing to total inequality. In our case, however, we have no variation in HK within the size categories of farms, making it impossible to decompose along this line. Also, we are investigating the change in inequality over time rather than the cross-section and its determinants.

[12] The Gini index is mainly popular for its intuitive interpretation in relation to the Lorenz curve. We find the Theil index preferable due to the mentioned reasons but also present results using the Gini index.

[13] See also Soltow (1979) and Meyer (1997) for other historical estimates of inequality in Denmark. Soltow finds extremely large estimates of wealth inequality in Denmark in 1789, with a Gini coefficient of 0.93. He uses tax returns which consider many sources of wealth, but the reason for his finding seems to be his allocation of land to the few hundred landowners, at a time when most land was effectively held by tenants. His approach thus differs fundamentally to ours. Meyer focuses on Copenhagen only at the turn of the nineteenth century, finding some equalization in the income distribution between 1789 and 1814.

[14] Reference Gini coefficients are taken from: World Bank, Development Indicators, Table 1.3. Downloadable at: wdi.worldbank.org/table/1.3. See also Deininger and Squire (1996, 1998) and Frankema (2010).

[15] Similarly, Lillo Bustos (2018), considering the case of Chile in the 1960s and '70s, found that a 1 standard deviation increase in the incidence of land reform at the municipality level resulted in a reduction of 21 percent in the Gini coefficient, as well as other positive outcomes such as improved educational attainment and better provision of public goods.

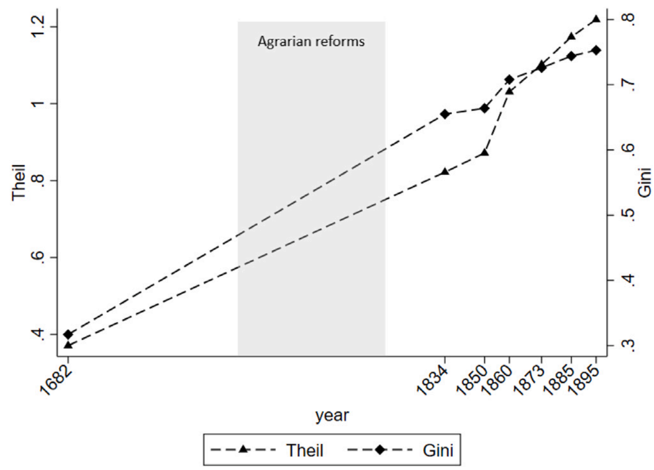


Fig. 3. Theil index and Gini coefficient for Denmark, 1682 to 1895.

it is again necessary to go back to the last ice age. Denmark was only partly covered in ice during the Weichselian glaciation approximately 18,000 years ago. As the ice retreated, the land in the ice-free parts of the country was eroded, leaving behind dry and sandy soil. The parts covered by ice, on the other hand, were left with markedly different soil with greater shares of clay and are much more suited to arable production. This phenomenon was first described by the Danish geologist Niels Viggo Ussing (Ussing, 1903, 1907) and provides us with the exogenous variation in the quality of soil within the country we exploit below. One might argue that we could use boulder clay directly, i.e. leaving out the step through total HK. However, it is not the soil type itself we hypothesize to have an impact on inequality but rather the productive capacity, which supports a greater population through better land management and technologies. Our thinking follows the strategy pursued by Fernihough and O'Rourke (2020), who identify the impact of coal extraction on development, where endogeneity might come from more developed areas having exploited this resource. Thus they instrument coal with an ancient geological feature which is associated with coal formation. In a similar vein, Danish soil is likely to have been considered to have been more productive in areas with more clay, but since the compilers of the HK measure were not aware of this association, this was not necessarily the case, with an obvious impact on expectations and management of the land.

We thus estimate the following model:

First-stage estimation:

$$\ln(Total HK)_p = \alpha + \beta \times BoulderClay_p + \lambda_r + X'_p\gamma + \epsilon_p \tag{2}$$

Second-stage estimation:

$$\Delta Theil_p = \alpha + \beta \times \ln(Total HK)_p + \lambda_r + X'_p\gamma + \epsilon_p \tag{3}$$

where $\ln(Total HK)_p$ is the natural logarithm of the total value of the land (measured in HK) of parish p, $BoulderClay_p$ is the share of parish area classified as boulder clay, λ_r represent regional fixed effects (defined as: Greater Copenhagen, Zealand, Funen, and Jutland) and $X'_p\gamma$ other geographical characteristics of parish p, including the natural logarithm of the parish area, the distance to Copenhagen, distance to the coast and the latitude and longitude of the parish. $\Delta Theil_p$ is the change in the Theil index for parish p from 1682 to 1834.[16]

Sometimes, the land belonging to one farm spans over more than one parish, say parishes A and B. In these cases, the reports allocate the share of the farm's HK belonging to the land in parish B to parish B. The farm itself, however, will only be included in parish A, where the actual building is placed. This is problematic, as parish B will then report 'too much' HK for its number of farms. Since we do not know the identity and parish affiliation of the farm in question, we add one farm to parish B in this case. If the amount of HK allocated to this one additional farm in parish B exceeds the upper boundary of the size category it is placed in, however, such that the average HK still exceeds its limits after adding one farm, we allocate the (closest integer) number of farms needed to reach the average of the category. For example, if in parish B there are 3 farms in the category *farms 12–8 HK* with a total of 42 HK, the average amount of HK for each farm is 14, which is above the upper limit of the size category, i.e. above 12. In this case, we add one extra farm, such that the average amount of HK is 10.5 and thereby within the size limits. If the total HK was 57, however, adding one farm would still leave the average per farm at 14.25 which is above the size limit. In this case, we would then add 2 farms, such that the average per farm is 11.4 and thus within the size limits of the category. Moreover, in 1850 four parishes have a positive value of HK for landless houses but no number of houses. In lack of a reference point for 1850, we replace the number of landless houses with one, which is in line with the average value of HK of landless houses in these parishes in other years. We calculate the Theil index both for the distribution with and without these corrections. The correlation between the corrected and the uncorrected Theil index is 0.98–0.99 for the years 1682–1885 and 0.95 in 1895.

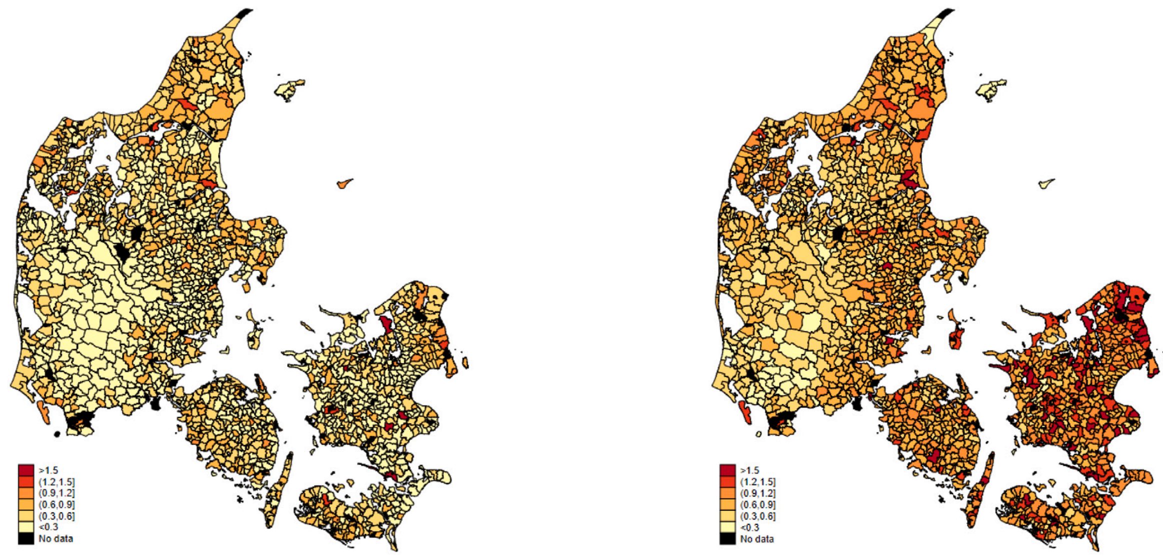
For the main results we use the maximum amount of information available in every year, i.e. we use the categories as they are given in each year. To check whether differences in the Theil index across years are only due to differences in the size categories, however, we aggregate categories in 1834 to the same (broader) categories of 1682 and in 1860 and 1873 to the categories of 1885/95. For the year 1834, the correlation between the Theil index using the aggregated categories and the original categories is 0.98 and Table 1 (column 4) shows that our results do not depend on the definition of categories. For 1860 and 1873 the correlation is 0.99.

We include landless houses into the calculation of the Theil index. Although they in general do not have a HK value (with the exception of 9 parishes in 1850 which assign a small value), they are counted in the total number of farms. Excluding them, and thus calculating inequality between farms and houses with land only, would generally result in a lower value of the Theil index. Summary statistics for the variables used can be found in Table A.1 in the Appendix.

5.2. Results

Estimation results of Eqs. (2) and (3) can be found in Table 1. The instrument is very strong in the first stage, which is not very surprising as both boulder clay and total HK represent a measure of soil quality (where boulder clay is exogenously determined by the extent of the glacial cover and the total HK was subjectively determined by an individual assessment of the value and productivity of the land). Thus, higher shares of boulder clay imply higher quality of land in terms of total HK assessment. Column (3) shows the second stage estimation for the change in the Theil index from 1682 to 1834. There is a strong positive relation between soil quality and inequality. A one standard deviation increase in total HK above the mean leads to an increase of 0.3 standard deviations in the change in the Theil, or a 25 percent increase above the mean change in inequality. Alternatively, moving from the 5th to 95th percentile in soil quality implies a 3.5 standard deviations increase in the change in Theil, representing an increase of almost three times the mean change in inequality. For reference, column (4) presents the reduced form, which reflects the strong first stage. Column (5) repeats the second stage estimation using the same size categories as in 1682 in the calculation of the Theil index in 1834. This is to show that the increase in the Theil index is not due to different size classifications of farms. Finally, column (6) uses the Gini coefficient

[16] We use absolute differences here because equal increases in the Theil reflect equal increases in inequality.



(a) 1682 (b) 1834

Fig. 4. Theil index of land inequality in Denmark, 1682 and 1834.

Table 1
IV estimation using total HK and the share of parish area classified as boulder clay.

	(1) OLS $\Delta Theil$	(2) 1st stage $\ln(TotalFarmHK)$	(3) 2nd stage $\Delta Theil$	(4) reduced form $\Delta Theil$	(5) 2nd stage $\Delta aggTheil$	(6) 2nd stage $\Delta Gini$
ln(TotalHK)	0.042*		0.164***		0.126***	0.101***
	(0.022)		(0.041)		(0.041)	(0.022)
boulder clay		0.750***		0.123***		
		(0.045)		(0.030)		
Region FE	Y	Y	Y	Y	Y	Y
Geography	Y	Y	Y	Y	Y	Y
Observations	1605	1605	1605	1605	1605	1605
R-Square	0.29	0.59	0.26	0.30	0.27	0.17
KP F-statistic			280.11		280.11	280.11

Geography controls include the natural logarithm of the parish area, the distance to Copenhagen, distance to the coast and the latitude and longitude of the parish. Regions are defined as: Greater Copenhagen, Zealand, Funen, and Jutland. Robust standard errors in parentheses.
*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$.

instead of the Theil index, and similar results are apparent.[17] We are therefore confident that our results do not rest on the chosen inequality metric, such that areas with higher soil quality saw greater increases in inequality throughout the period of reforms.

Fig. 5 shows the estimates of the second stage coefficients in levels for the years 1682 to 1895, the outcome variable in the second stage is thus $\ln(Theil)$ in the different years rather than the change in the Theil.[18] As was already to a certain extent apparent from the maps in Figs. 1 and 3, there is no significant relation between soil quality and inequality before the reforms, in 1682. Only from 1834 onwards do we see a strong positive effect of soil quality on inequality. This pattern seems to stabilize after 1850, where the positive relation between soil quality and inequality remains strong and the estimated coefficient is remarkably stable up to 1895. The land reforms thus appear to be a major determinant of land inequality throughout the nineteenth century.

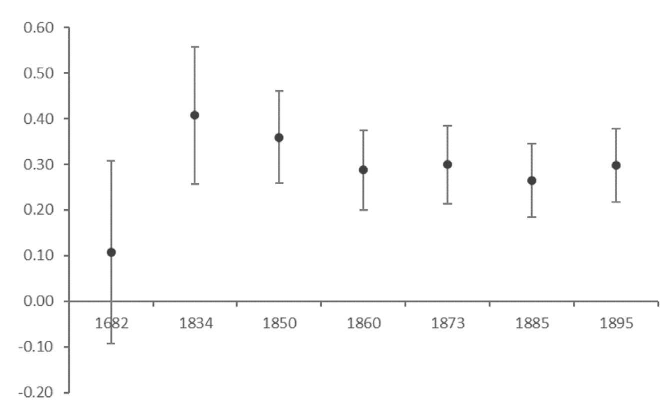


Fig. 5. Coefficients from second stage estimations, 1682 to 1895. Dependent variable: $\ln(Theil)$, instrument: *share of boulder clay*, controls included.

[17] Table A.3 in the Appendix also shows level results using the Gini coefficient and again, the results are essentially the same as in Fig. 5, below.

[18] Note that each plotted beta represents the point estimate from a separate regression. We find this preferable, as it allows to show that there is no significant relation in 1682, which would not be apparent from a difference-in-differences setup.

5.3. Robustness checks

We conduct several robustness checks to verify our results. First, we use a different measure of land value. In the main analysis, we used the value of land measured in total HK, which includes all types of crops. One could argue that the relevant measure to look at is how much barley could be produced on the land, as this was the main crop at the time. Barley was most suited for the Danish climate as it has a short growing time, does not easily bend over, and can take more salt in the water than, for example wheat.[19] We therefore, instead of the total value of HK of the parish, measure land quality only by the amount of barley paid in tax. We take this measure from digitizing a map presented by Frandsen (1988). Results can be found in the Appendix in Table A.4 and are very similar to our main estimations. There is a strong positive relationship with the change in inequality. As a further robustness check, we present results for the more widely used measure of land suitability published by FAO, instead of the share of the parish area classified as boulder clay, which is of course very specific to the Danish case. These results can be found in appendix Table A.5 and, again, show little difference to our main results.

Finally, as with any spatial analysis, there is the risk that we are merely capturing spatial correlation over time. We therefore randomize first the outcome variable ($\Delta Theil$), second the main explanatory variable of interest ($\ln(TotalHK)$), and third the instrument (*boulder clay*) in the parish. We then re-estimate the preferred model (columns (3) and (4) in Table 2) 10,000 times using the randomized variable instead of the observed variable one at a time. The estimated t-values on the second stage coefficient on $\ln(TotalHK)$ are reported in Fig. A.2 in the Appendix. Clearly, the observed variable outperforms the randomized variable in all three cases. We also present results using Conley standard errors for different cut-off points in Table A.6 in the Appendix. The significance of the estimate is not affected.

6. Mechanisms

6.1. Population growth

As noted above, we propose a Malthusian mechanism for our findings through population growth. Areas with higher soil quality benefited relatively more from the agrarian reforms, meaning that more people could be supported from the land. To investigate this further, we use population data from the censuses taken during our time period and calculate population density on the parish level, defined as total population by parish area. Again, the first stage is as defined in Eq. (2) and the second stage now takes the following form:

$$\Delta ln(pop)_{p,1769/t} = \alpha + \beta \times \ln(TotalHK)_p + \lambda_r + X_p' \times \gamma + \epsilon_p \quad (4)$$

where $\Delta ln(pop)_{p,1769/t}$ is the change in the natural logarithm of population from 1769 to year t in parish p. The rest is as defined before. Estimation results from these separate regressions are shown in Fig. 6. Population growth shows a small increase during the initial stages of the reforms in areas with higher soil quality. After complete implementation, however, this increase takes off, where the point estimate almost doubles, and thereafter stabilizes. This pattern can also be observed in Fig. A.3 in the Appendix, where we provide maps of changes in population densities for the years 1769–1895. From 1769 to 1834 population density increases at a much higher rate, but also much more so in certain areas, resembling very much the pattern of inequality in Fig. 4.[20] After 1834, population densities grow rather uniformly (apart from the area of Copenhagen), and even start to decline in some areas in the later years, possibly due to emigration from overpopulated areas, which took off from the 1880s (Hvidt, 1971).

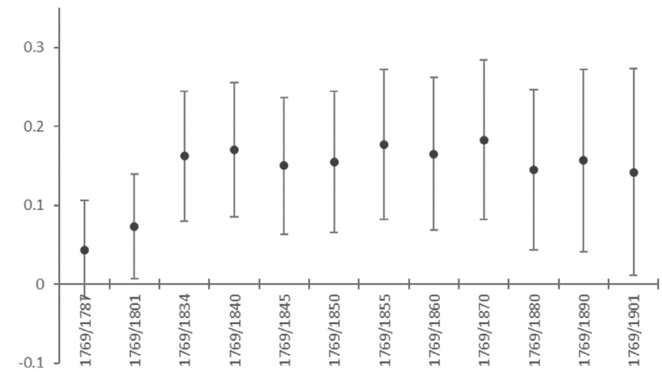


Fig. 6. Coefficients from second stage estimations, 1769 to 1901. Dependent variable: $\Delta ln(pop)$, instrument: *share of boulder clay*, controls included.

6.2. Fertility vs. migration

One issue with our proposed mechanism might be that more productive areas attracted more people after the agrarian reforms, during which adscription and restrictions to labor mobility were eased. Although it seems unlikely that internal migration could be the main cause of changes in relative inequality, we nevertheless proceed to calculate measures of internal migration as well as fertility so that we can investigate their relative contribution to population increases. We calculate fertility measures on the parish level using the micro data of the Danish population censuses from 1787, 1801, 1834, 1850 and 1870 (Danish National Archives, 1787, 1801, 1834, 1850; Statistiske Bureau, 1911). Fertility is defined as the number of children under the age of five per married woman (age 15–54) in the parish. We are thus looking at *recent net fertility* as only children (currently) alive are considered, thus not taking account of child mortality. This measure has become a standard way to measure fertility from census data (see Hacker, 2016; Dribe et al., 2014; Dribe and Scalone, 2014). As for internal migration, it is first possible to calculate this in 1850, since previous censuses do not report the place of birth. In 1850 we are able to locate the birthplace of 88 percent of the census observations to an *amt* in Denmark or to a place outside of Denmark. The measure of migration thus also includes immigrants from outside of Denmark. Outmigration from Denmark was registered from 1868, after it increased in the 1860s and then accelerated from the 1880s. There was very little outmigration before 1850, so our measure of internal migration and international immigration should capture the majority of migration for this period. *Amt* was a larger administrative unit and Denmark was divided into 24 amts in 1850.[21] Migration is then defined as the number of people living in parish p in amt a, not being born in amt a, divided by the population of parish p with known birthplace. We then estimate the following model:

$$ln(pop)_{p,t} = \alpha + \beta_1 \times \ln(fertility)_{p,t} + \beta_2 \times \ln(migration)_{p,1850} + \lambda_r + X_p' \times \gamma + \epsilon_p \quad (5)$$

The results are presented in Table 2. Column (1) shows the pooled OLS estimation for all years. Year fixed effects are only included in column 1, since migration is only available in 1850. Column (2) shows the same estimation for 1870 only, i.e. fertility from 1850, to make the result comparable to columns (3) and (4). Column (3) shows the estimation for migration only, and column (4) for including both fertility and migration.

[19] See http://www.emu.dk/erhverv/miljoe/Miljoetemaer/biodiv/biodiv.html.

[20] In line with a Malthusian explanation, we find a positive relation of population levels with soil quality (measured by total HK) throughout the whole period.

[21] We use 18 amts in this paper, as we are excluding the island of Bornholm and Southern Jutland, because these regions are not reported consistently, as mentioned earlier.

Table 2
OLS estimation including possible mechanisms: fertility and migration.

	(1) ln(pop) 1801–1870	(2) ln(pop) 1870	(3) ln(pop) 1870	(4) ln(pop) 1870
L.ln(fertility)	0.157***	0.196***		0.192***
	(0.027)	(0.073)		(0.073)
L.ln(migrated)			0.053***	0.052***
			(0.016)	(0.016)
Year FE	Y	N	N	N
Region FE	Y	Y	Y	Y
Geography	Y	Y	Y	Y
Observations	6292	1573	1573	1573
R-squared	0.65	0.58	0.58	0.59

Geography controls include the natural logarithm of the parish area, the distance to Copenhagen, distance to the coast and the latitude and longitude of the parish. Regions are defined as: Greater Copenhagen, Zealand, Funen, and Jutland. Robust standard errors in parentheses.
*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$.

Clearly, there is strong positive correlation with fertility and subsequent population growth. This is true for the whole period, as well as the cross-section in 1870. While migration is also positively correlated with population growth, column (4) shows that the elasticity with fertility is around four times the elasticity with migration, while both variables have similar standard deviations (see Table A.1). Of course, this result has no causal interpretation, but it nevertheless provides some evidence in favor of the Malthusian mechanism.

While we believe that the Malthusian mechanism should have been active in similar settings in other countries as well, it might be that the institutional design of Danish agriculture and the land reforms favored an outcome where increasing population led to more land inequality instead of equally distributed smaller farms. The land reforms built on the idea of keeping the existing family farms, which had been protected from dissolution under Danish absolutism before, intact, and thus provided advantageous conditions to their current tenants. Smallholders and cotters did not enjoy similarly favorable conditions and thus faced greater difficulties in access to land in the transition (Henriksen, 2003). Impartible inheritance of farms to avoid farm division also had a tradition going back at least to 1769, loosened in the immediate reform period, but reinforced at least since the 1830s through all of the nineteenth century (Jensen, 1945).

6.3. Houses

We propose that the population growth led to a larger share of the population having no access to land. This will of course only be true if the number of farms does not change and if the average size of farms does not change. As noted earlier, historical evidence indicates that the number of farms stayed relatively constant throughout the period. We can, however, also analyze this more formally. Fig. 7 shows the average sizes of medium-sized farms in 1682 and 1834 across regions in the left panel.[22] Clearly, the average size of medium sized farms stays rather constant before and after the reforms (left panel). This indicates that the increase in land inequality is not just due to a decrease in farm sizes. We do, however, see an increase in the number of houses with very little (below 1 HK) or no land attached (right panel). There is thus an increasing share of the population who do not have access to land. This finding is supported by the fact that the Theil index increases relatively more when including landless houses in its calculation. Using the same size categories in both years, the Theil index for Denmark as a whole in 1682 is 0.37 including landless houses and 0.25 excluding them. This figure increases to 0.69 including and to 0.51 excluding landless houses.

The category of medium-sized farms can only be consistently displayed for the years 1682 and 1834. It is, however, also interesting to see how the different size categories evolve over the following century. The category of 'houses' is always defined as a unit with land of 1 or less HK. Fig. 8 shows the absolute number of houses across years (left panel) and their share in the total number of productive units in the parish (right panel). In addition, we can form a coherent category of farms with a size between 1 and 8 HK for the years 1834–1895. These represent farms of medium size.[23] The absolute number of these farms as well as their share in the total number of productive units in the parish is displayed in Fig. 8 alongside the houses.

Clearly, the number of houses, as well as their share in the parish, increased dramatically over time whereas there is very little change in the number and share of farms of medium size (1–8 HK). In order to examine whether this was more so the case in parishes with better soil quality, we repeat the econometric analysis of Eq. (4) but replace the (long) differences in population with the corresponding (long) differences in the share of houses in the total number of productive units in the parish. As above, the second stage coefficients are presented in Fig. 9). The coefficient is already positive for the change from 1682 to 1834, i.e. over the reforms but becomes first significant for the change from 1682 to 1850. Also, the coefficient turns insignificant later during the period — as was also the case with population changes above. As mentioned earlier, we propose this may be due to overseas emigration.

6.4. Agricultural productivity

As evident from Fig. 1, we propose that the agrarian reforms increased agricultural productivity, especially in areas with better soil quality. To examine this, we examine the change in the amount of seedings from 1837 to 1861. Here, we do not have data from before the reforms, but using first differences we investigate whether seedings increased more in areas with high soil quality than in other areas. To avoid capturing changes in the crop mix, we add seedings of the main crops of the time: barley, wheat, rye, and oats. The amount of seedings is provided in HK in the agrarian censuses. We use three different conversion rates to add these three crops to a total amount of seedings. First, we use conversion rates according to *foderenhed* (unit of feed) (Bjørn, 1982), which standardizes barley/wheat/rye/oats into the same amount of fodder.[24] We denote this conversion 'FE' in the following. Second, we apply conversion rates of the 1844 HK classification.[25] We denote this conversion 'HK' in the following. Third, we apply the caloric value of the grains as provided by the U.S. Department of Agriculture (2019).[26] This conversion is denoted with 'kcal'. We further use the animal counts of cows and pigs to measure agricultural productivity, with the assumption that more efficient use of the land can also support larger herds. We then estimate the effect of soil quality on agricultural productivity, again using our instrument of share of

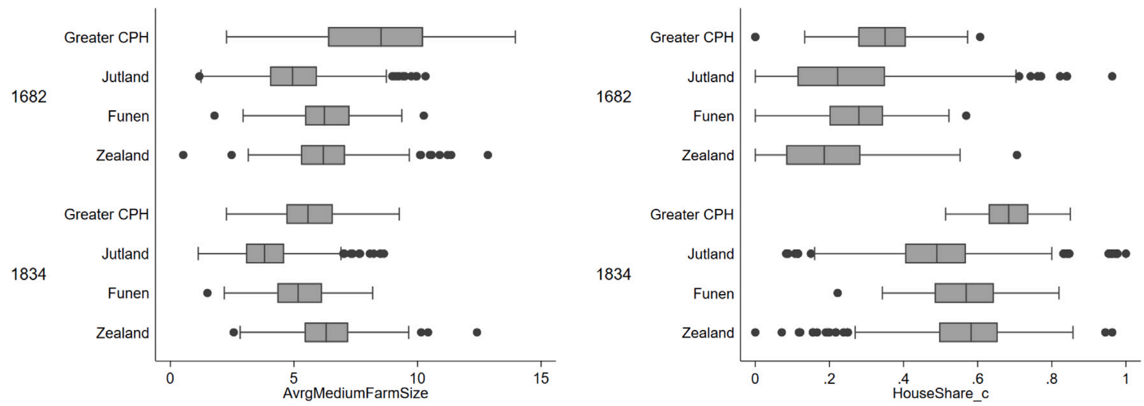
[22] In the years 1682 and 1834 large farms are classified as 'manors'. We define a medium-sized farm as any farm below this category and with more than 1 HK of land. Units with 1 or less HK are defined as 'houses'. See also appendix Table A.2.

[23] But are not exactly the same as the medium-sized farms in Fig. 7a because this can also include farms above 8 HK as long as it is not classified as a manor. Note that we cannot form this category in 1682 as we only have the categories 'manors' and 'farms' in this year. The 1682 data reported 57,000 farms (excl. manors and houses with or without land) which made up 72 percent of the reported units.

[24] 1 kg of barley, wheat or rye corresponds to 1.2 kg of oats.

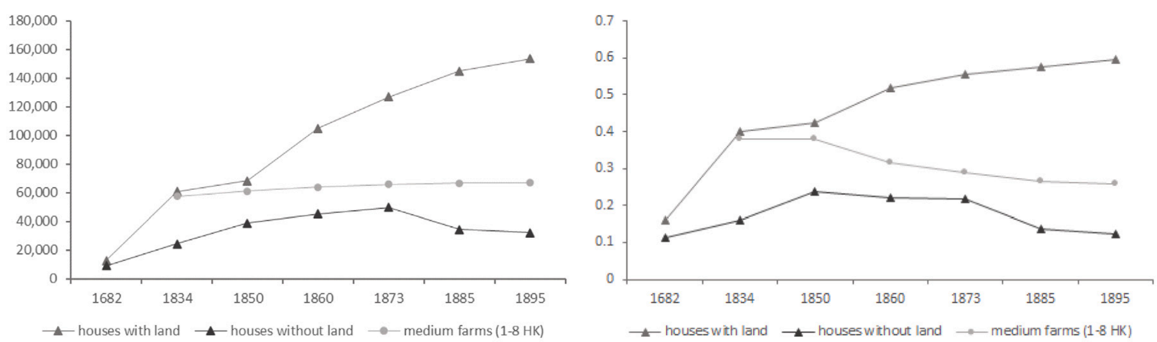
[25] Here, 1 unit of barley or rye corresponds to 1.5 units of wheat and 2 units of oats.

[26] Here, 100 g of barley flour contain 345 kcal, 100 g of rye flour 325 kcal, 100 g of wheat flour 332 kcal, and 100 g of oat flour 404 kcal.



(a) Average farm size (b) Share of 'houses'

Fig. 7. Number of houses and medium-sized farms, 1682 to 1895.



(a) Absolute numbers (b) Shares

Fig. 8. Number of houses and farms of medium size (1–8 HK) in absolute numbers and as shares of total productive units, 1682 to 1895.

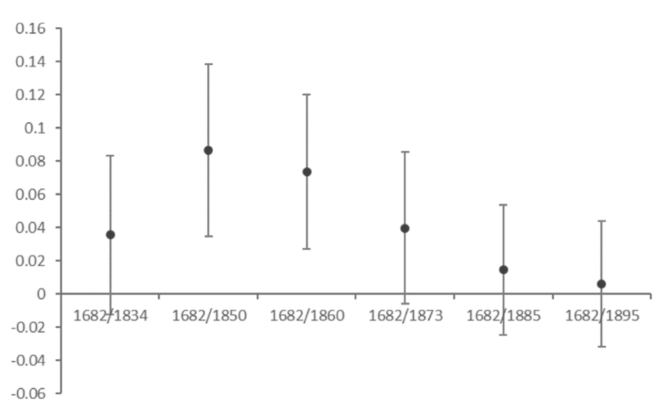


Fig. 9. Coefficients from second stage estimations, 1769 to 1901. Dependent variable: $\Delta HouseShare$, instrument: *share of boulder clay*, controls included.

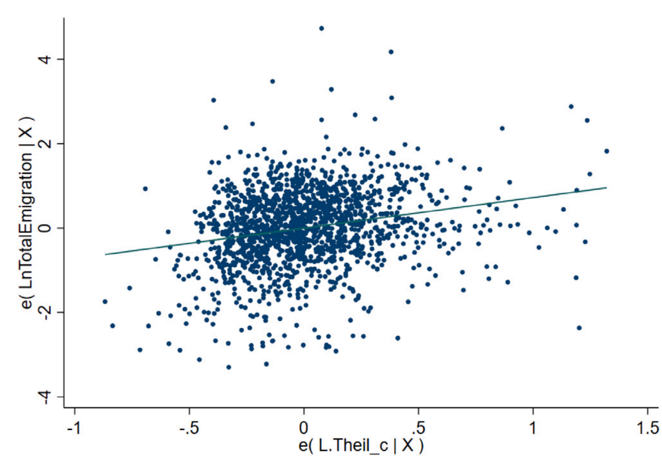
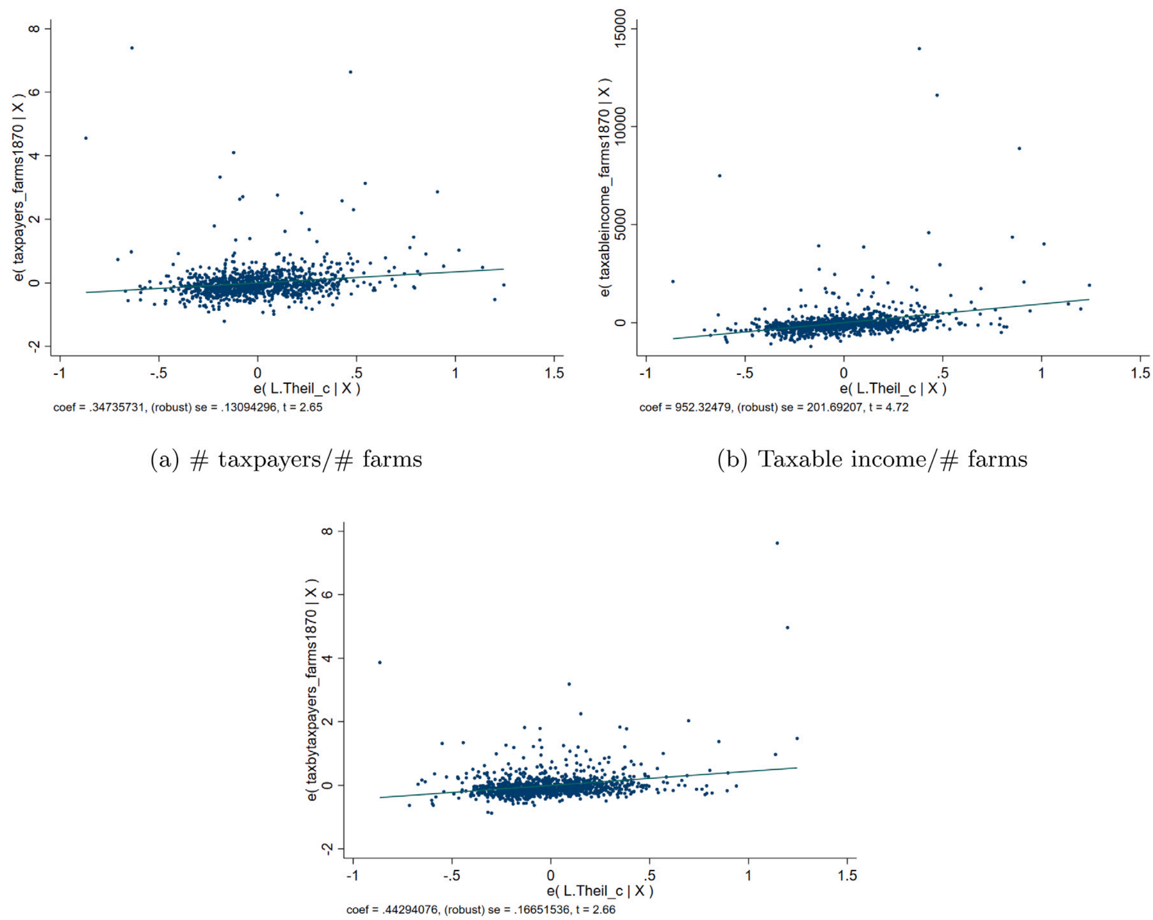


Fig. 10. OLS coefficient of $Theil_{p,1860}$, dependent variable: $\ln(Emigration_{p,1860--1908})$, controls included.



(a) # taxpayers/# farms

(b) Taxable income/# farms

(c) Avrg. tax per taxpayer/# farms

Fig. 11. OLS coefficients of $Theil_{p,1860}$, controls included.

boulder clay in the parish. The first stage is as defined in Eq. (2). The second stage now takes the following form:

$$\Delta Y_{p,1837/1861} = \alpha + \beta \times \ln(TotalHK)_p + \lambda_r + X'_p \times \gamma + \epsilon_p \quad (6)$$

where $\Delta Y_{p,1837/1861}$ is the change in one of our outcome variables (change in total seedings, change in the natural logarithm of the number of cows/pigs) from 1837 to 1861. The rest is as defined earlier. The results can be found in Table 3.

In columns (4)–(7) we control for the butter-to-grain ratio, given by taxes paid on butter to taxes paid on grains (barley and rye) in 1682 (Frandsen, 1988). We include this as a measure of pre-reform specialization in animal agriculture. In columns (5) and (7) we further control for the initial stock of cows/pigs in 1837 to capture convergence effects. We find significant increases in all three measures of agricultural productivity, using all three conversion rates. Thus, agricultural productivity increased significantly more in areas with high soil quality.

7. Effects of inequality

Finally, we consider the impact of agrarian reform, both on the winners and the losers. We already noted above that the relationship between land inequality and for example population growth disappears by the end of the nineteenth century and we suggested that this was due to emigration, especially to the United States. We therefore correlate the level of inequality in 1860 with subsequent emigration from the parish. As of 1860, every emigrant had to register with the police. We use these police records to calculate the number of emigrants from the parish (Det Danske Udvandrerarkiv, 2018). The data is available until 1908 and thus captures the main period of Danish emigration. We estimate the following OLS model:

$$\ln(Emigration_{p,1860-1908}) = \alpha + \beta \times Theil_{p,1860} + \lambda_r + X'_p \times \gamma + \epsilon_p \quad (7)$$

where $\ln(Emigration_{p,1860-1908})$ is the natural logarithm of the total number of people who emigrated from parish p between 1860 and 1908. Fig. 10 provides an added variable plot of the proposed relationship, and suggests support for our proposed mechanism: parishes with more 'losers', with little or no land, witnessed greater emigration. This also suggests a negative selection of overseas emigrants, in line with Knudsen (2021) who finds evidence for cultural selection in a wider Scandinavian context.

Turning to the 'winners', we investigate the effect of inequality on (top) incomes. Here, we use data from the tax registers of 1870 (Statistiske Bureau, 1873). This provides us with the number of tax payers in a parish, total taxable income, and total tax paid — from which we calculate the average tax paid by taxpayer. We scale these variables by the total number of farms in the parish. Fig. 11 shows the correlation of inequality in 1860 with the number of tax payers per total number of farms, total taxable income per total number of farms, and average tax paid by taxpayer per total number of farms.[27] Note that the number

[27] We choose to scale by the number of farms, here, because this is rather constant over our period. The same graphs scaled by population can be found in the Appendix. Note that here, parishes with higher inequality will also have larger populations following from Section 6.1. It is therefore not surprising that we find a negative relation of the number of taxpayers with inequality in this case.

Table 3
Second stage estimates for agricultural productivity, instrument: *share of boulder clay*.

	(1) D.seedings (FE)	(2) D.seedings (HK)	(3) D.seedings (kcal)	(4) D.lnCows	(5) D.lnCows	(6) D.lnPigs	(7) D.lnPigs
ln(TotalHK)	276.247***	195.621***	103.165***	0.064**	0.283***	−0.194**	0.272***
	(30.617)	(23.382)	(11.405)	(0.027)	(0.042)	(0.077)	(0.067)
lnCows1837					−0.371***		
					(0.036)		
lnPigs1837							−0.679***
							(0.029)
butter_to_grain				−0.002	0.015	0.022	0.030
				(0.011)	(0.010)	(0.027)	(0.019)
Region FE	Y	Y	Y	Y	Y	Y	Y
Geography	Y	Y	Y	Y	Y	Y	Y
Observations	1606	1606	1606	1483	1483	1483	1483
R-squared	0.33	0.29	0.34	0.20	0.34	0.12	0.59
KP F-statistic	251.27	251.27	251.27	486.61	394.10	486.61	428.65

Geography controls include the natural logarithm of the parish area, the distance to Copenhagen, distance to the coast and the latitude and longitude of the parish. Regions are defined as: Greater Copenhagen, Zealand, Funen, and Jutland. Robust standard errors in parentheses.
*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$.

of parishes is reduced to 1000 here as one tax parish usually included two church parishes.

There are a number of outliers. These are mainly parishes which are on the edge of urban areas, for example Frederiksberg which borders Copenhagen. There are thus a large number of houses whose owners pay taxes. This means they are counted as taxpayers but the houses do not count in the number of farms. These are excluded from the scatter plots above for better visibility[28]: see appendix Table A.7 for the estimations of this section where outliers are included.

We find a positive relation between the number of taxpayers per number of farms with inequality, see panel 11a in Fig. 11. Consequently, we also find a positive correlation with total taxable income per number of farms. There is also a, somewhat weaker but still significant, positive correlation with the average tax paid by taxpayer per number of farms. This indicates that the more unequal parishes had a greater landless population but at the same time also more taxpayers, i.e. greater population at the other end of the income scale. In addition, these top income earners were richer in more unequal parishes as indicated by the higher average tax paid in these parishes. This might of course also be a consequence of these parishes having the best soil. The historical literature on enclosures suggests, however, that the main potential benefit of the expansion of the private ownership of land and the consolidation of holdings was to reduce the transaction costs involved in introducing more advanced agricultural techniques (Slicher van Bath, 1963, 1977; Overton, 1996a,b).

8. Conclusion

We have demonstrated that land inequality in Denmark increased more in areas with better quality soil over the course of agrarian reforms, and that this was the result of greater concentrations of people with little or no land. This highlights that land reform can have negative effects as well as positive. We believe that this holds lessons for policy today, at least where similar constraints exist, such as a desire to maintain a certain minimum size of family farms, or where they cannot be divided for institutional reasons. In the Danish case, medium-sized farmers gained from the reforms, which are considered to have been a necessary condition for enabling the rise of the cooperatives, and the massive increases in productivity in agriculture which to a large extent characterizes the Danish development story (see for example Lampe and Sharp, 2019a). Cotters and landless laborers lost, however, and were not to be compensated until further reforms in the twentieth century, by which time many had chosen to leave for the New World or urban settings in Denmark. Thus, the winners went on to define present Denmark, whereas the losers took their outside option, and as we argued earlier, this opportunity might go some way to explaining the sustainability of the Danish pro-efficiency reforms. Although one should of course be careful not to overplay historical parallels, we believe that modern day development programs seeking to follow the same path might take note. Given the rich world's restrictions on agricultural imports as well as their immigration controls, there is reason to believe that the consequences of agrarian reform might be particularly severe in modern settings.

CRediT authorship contribution statement

Nina Boberg-Fazlić: Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing, Funding acquisition. **Markus Lampe:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing, Funding acquisition. **Pablo Martinelli Lasheras:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing, Funding acquisition. **Paul Sharp:** Conceptualization, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition.

Data availability

Data will be made available on request.

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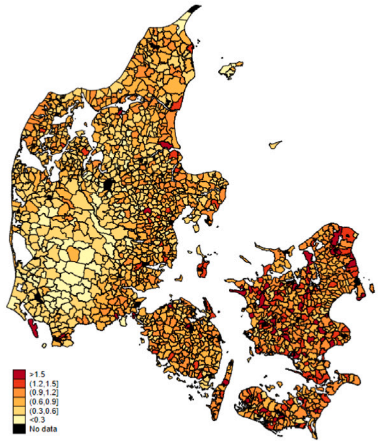
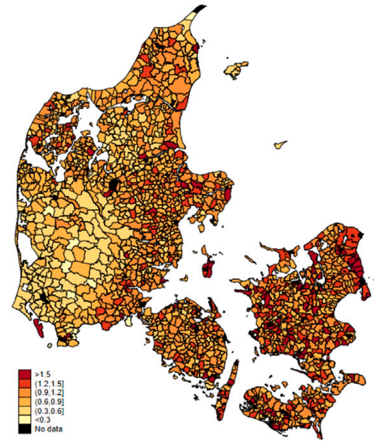
Appendix

See Figs. A.1–A.4 and Tables A.1–A.7.

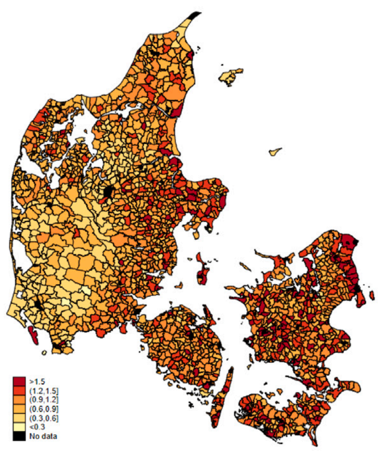
[28] This means we exclude observations with $\#taxpayers/\#farms >= 10$ in panel 11a, $Taxableincome/\#farms >= 20{,}000$ in panel 11b, and $Avrg.taxpertaxpayer/\#farms >= 10$ in panel 11c.



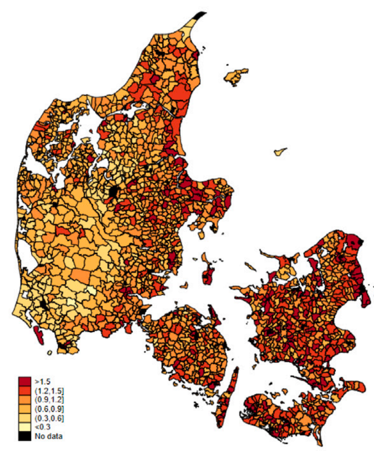
(a) 1850



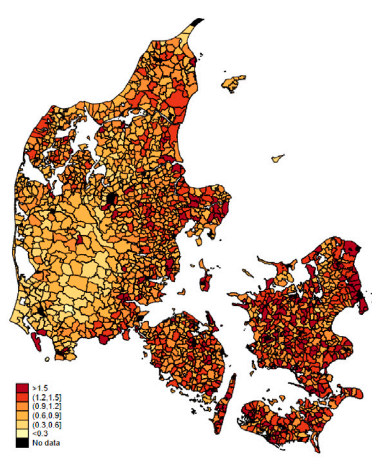
(b) 1860



(c) 1873

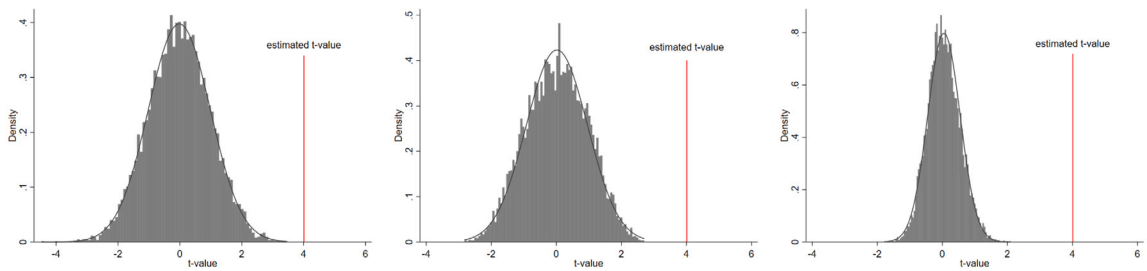


(d) 1885



(e) 1895

Fig. A.1. Theil index of land inequality in Denmark, 1850 to 1895.



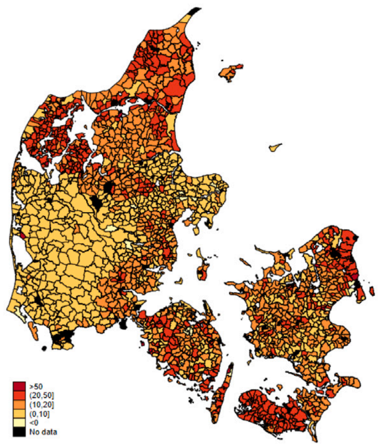
(a) ln($Theil$) randomized (b) ln($TotalHK$) randomized (c) *boulder clay* randomized

Fig. A.2. T-values of second stage estimation on $\ln(TotalHK)$, randomizing: (a) the outcome variable, (b) explanatory variable, (c) instrument.

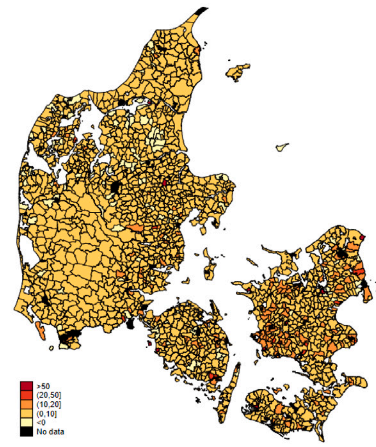
Table A.1
Summary statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
TotalHK 1682	1,605	218.5	140.8	4.3	1,089.3
TotalHK 1834	1,605	220.7	141.6	2.3	1,048.4
TotalHK 1850	1,605	221.6	140.1	7.5	1,287.4
TotalHK 1860	1,605	221.1	139.4	8.7	1,287.9
TotalHK 1873	1,605	221.6	139.6	6.9	1,297.9
TotalHK 1885	1,605	221.9	139.8	7.0	1,302.3
TotalHK 1895	1,605	223.3	148.8	7.0	2,297.1
TotalFarmNr 1682	1,605	49.9	32.2	3	262
TotalFarmNr 1834	1,605	94.2	65.9	8	763
TotalFarmNr 1850	1,605	100.8	68.9	4	759
TotalFarmNr 1860	1,605	127.0	89.3	7	1,026
TotalFarmNr 1873	1,605	142.6	99.7	9	1,138
TotalFarmNr 1885	1,605	156.8	114.9	12	1,666
TotalFarmNr 1895	1,605	160.9	128.4	12	2,204
Theil 1682	1,605	0.35	0.25	0.02	2.08
Theil 1834	1,605	0.75	0.35	0.00	3.02
Theil 1850	1,605	0.76	0.33	0.08	2.81
Theil 1860	1,605	0.90	0.32	0.11	2.51
Theil 1873	1,605	0.96	0.34	0.16	2.51
Theil 1885	1,605	1.02	0.35	0.17	3.13
Theil 1895	1,605	1.05	0.37	0.19	4.54
Gini 1682	1,605	0.28	0.15	0.02	0.88
Gini 1834	1,605	0.58	0.12	0.00	0.93
Gini 1850	1,605	0.59	0.11	0.19	0.94
Gini 1860	1,605	0.65	0.09	0.18	0.92
Gini 1873	1,605	0.67	0.09	0.29	0.93
Gini 1885	1,605	0.69	0.09	0.30	0.95
Gini 1895	1,605	0.70	0.09	0.32	0.97
Population 1769	1,605	295.0	327.9	0	4,425
Population 1834	1,605	597.4	502.9	47	7,894
Population 1850	1,605	686.8	583.6	42	8,932
Population 1860	1,605	764.8	686.4	44	10,203
Population 1870	1,605	837.6	833.9	49	16,878
Population 1880	1,605	890.6	1,040.8	56	26,510
Population 1890	1,605	930.0	1,503.3	60	46,954

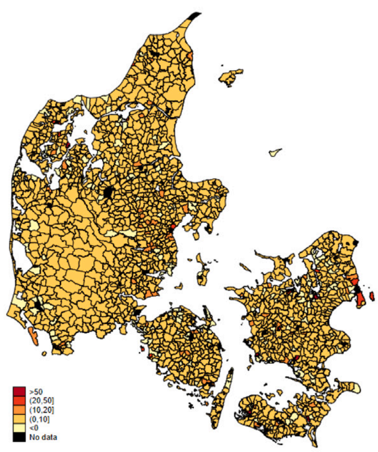
Variable	Obs	Mean	Std. Dev.	Min	Max
Fertility 1787	1,571	0.68	0.17	0.14	3.63
Fertility 1801	1,571	0.41	0.11	0.06	0.90
Fertility 1834	1,571	0.74	0.18	0.30	4.69
Fertility 1850	1,571	0.76	0.13	0.32	1.60
Migrated (population share)	1,571	0.11	0.10	0.00	0.82
Number of cows 1837	1,605	337.0	219.3	0	2048
Number of cows 1861	1,605	443.2	278.5	0	3065
Number of pigs 1837	1,605	134.0	141.1	0	1835
Number of pigs 1861	1,605	173.6	147.5	0	1732
Total seedings (FE) 1837	1,605	808.8	466.0	0	4,132.1
Total seedings (FE) 1861	1,605	1,123.9	631.6	0	6,504.8
Total seedings (HK) 1837	1,605	683.8	398.8	0	3,416.5
Total seedings (HK) 1861	1,605	910.9	512.3	0	5,145.3
Total seedings (kcal) 1837	1,605	289.8	166.7	0	1,493.7
Total seedings (kcal) 1861	1,605	408.0	229.8	0	2,381.7
BarleyLG	1,605	3.5	3.1	0	23
ShareBoulderClay	1,605	0.48	0.32	0	1
AreaSogn	1,605	22.6	18.4	1.7	184.1
Distance to Copenhagen	1,605	165.8	75.6	2.8	295.1
Lat	1,605	6,210	76	6,056	6,396
Long	1,605	579	74	447	730
Distance to coast	1,605	7.9	7.3	0.02	44.6
Total emigration	1,577	64.7	100.4	1	1,467
Income taxpayers 1870	1,013	97.0	91.7	6	2,264
Taxable income 1870	1,013	75,897	101,895	2,675	2,766,325
Avrg. tax paid per taxpayer	1,013	24.8	15.3	3.3	146.1



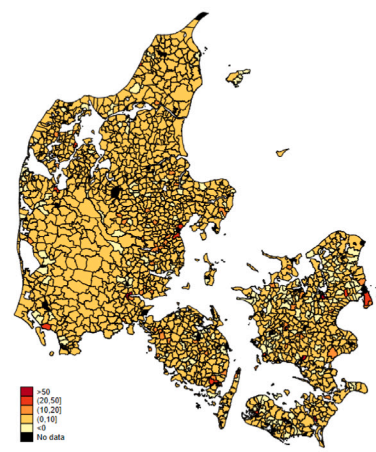
(a) 1769-1834



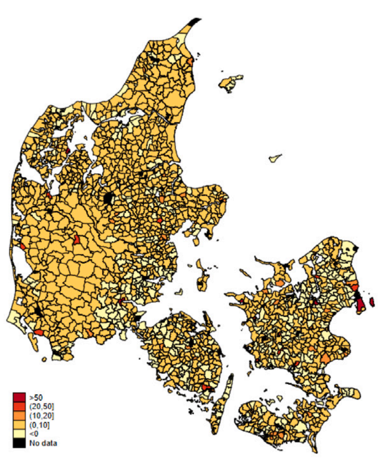
(b) 1834-1850



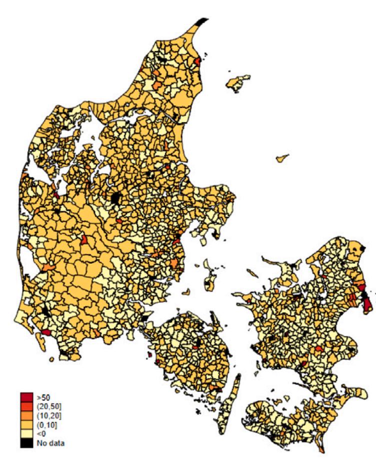
(c) 1850-1860



(d) 1860-1870

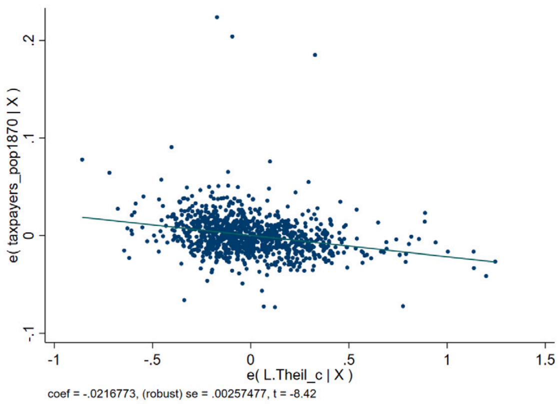


(e) 1870-1880

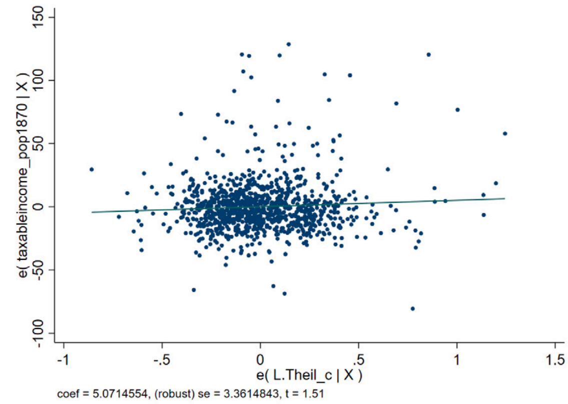


(f) 1880-1890

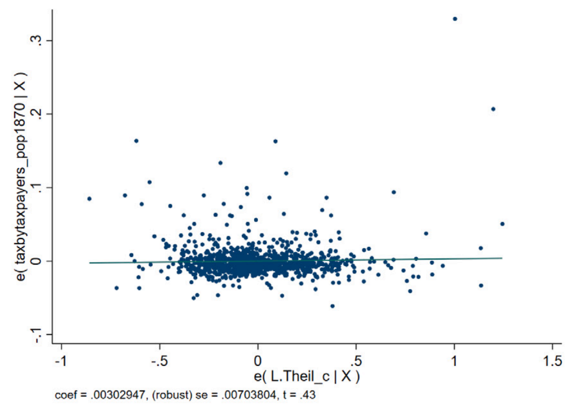
Fig. A.3. Change in population density, 1769 to 1890.



(a) Taxpayers by population



(b) Tax paid by population



(c) Average tax per taxpayer by population

Fig. A.4. OLS coefficients of $Theil_{p,1860}$, controls included.

Table A.2
Classification scheme of land reports of farms and houses into types and sizes (in *tønder hartkorn*), 1682–1895.

1682	1834	1850	1860	1873	1885	1895
Manors	Complete Manors		Full property > 30	Full property > 30		
	Uncomplete Manors		Full property 20 - 30	Full property 20 - 30	Farms > 20	Farms > 20
	Unprivileged Manors	Full property > 12	Full property 12 - 20	Full property 12 - 20	Farms 12 - 20	Farms 12 - 20
Farms	Full property > 8	Full property 8 - 12	Full property 8 - 12	Full property 8 - 12	Farms 8 - 12	Farms 8 - 12
	Full property 4 - 8	Full property 4 - 8	Full property 4 - 8	Full property 4 - 8	Farms 4 - 8	Farms 4 - 8
	Full property 2 - 4	Full property 2 - 4	Full property 2 - 4	Full property 2 - 4	Farms 2 - 4	Farms 2 - 4
	Full property 1 - 2	Full property 1 - 2	Full property 1 - 2	Full property 1 - 2	Farms 1 - 2	Farms 1 - 2
			Hereditary >30	Hereditary >30		
			Hereditary 20 - 30	Hereditary 20 - 30		
			Hereditary 12 - 20	Hereditary 12 - 20		
	Hereditary >8	Hereditary 8 - 12	Hereditary 8 - 12	Hereditary 8 - 12		
	Hereditary 4 - 8	Hereditary 4 - 8	Hereditary 4 - 8	Hereditary 4 - 8		
	Hereditary 2 - 4	Hereditary 2 - 4	Hereditary 2 - 4	Hereditary 2 - 4		
	Hereditary 1 - 2	Hereditary 1 - 2	Hereditary 1 - 2	Hereditary 1 - 2		
			Rented 20 - 30	Rented 20 - 30		
			Rented 12 - 20	Rented 12 - 20		
	Rented >8	Rented 8 - 12	Rented 8 - 12	Rented 8 - 12		
	Rented 4 - 8	Rented 4 - 8	Rented 4 - 8	Rented 4 - 8		
	Rented 2 - 4	Rented 2 - 4	Rented 2 - 4	Rented 2 - 4		
	Rented 1 - 2	Rented 1 - 2	Rented 1 - 2	Rented 1 - 2		
Houses	Full property < 1	Full property 0.25 - 1	Full property 0.25 - 1	Full property 0.25 - 1	Houses 0.25 - 1	Houses 0.25 - 1
		Full property 0.003 - 0.25	Full property 0.003 - 0.25	Full property 0.003 - 0.25	Houses 0.003 - 0.25	Houses 0.003 - 0.25
			Full property 0 - 0.003	Full property 0 - 0.003	Houses 0 - 0.003	Houses 0 - 0.003
	Hereditary < 1	Other houses 0.25 - 1	Other houses 0.25 - 1	Other houses 0.25 - 1		
	Rented < 1	Other houses 0.003 - 0.25	Other houses 0.003 - 0.25	Other houses 0.003 - 0.25		
			Other houses 0 - 0.003	Other houses 0 - 0.003		
Houses without land	Full property without land	Full property without land	Full property without land	Full property without land	Houses without land	Houses without land
	Hereditary without land	Other houses without land	Other houses without land	Other houses without land		
	Rented without land					

Table A.3
Robustness check: Second stage IV estimates using Gini coefficient.

	(1) 2nd stage *Gini* 1682	(2) 2nd stage *Gini* 1834
ln(TotalHK)	−0.006 (0.019)	0.094*** (0.017)
Region FE	Y	Y
Geography	Y	Y
Observations	1605	1605
R-Square	0.14	0.26
KP F-statistic	250.94	280.11

Geography controls include the natural logarithm of the parish area, the distance to Copenhagen, distance to the coast and the latitude and longitude of the parish. Regions are defined as: Greater Copenhagen, Zealand, Funen, and Jutland. Robust standard errors in parentheses.
*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$.

Table A.4
IV estimation using barley payments and the share of parish area classified as boulder clay.

	(1) OLS $\Delta Theil$	(2) 1st stage $ln(TotalFarmHK)$	(3) 2nd stage $\Delta Theil$	(4) 2nd stage $\Delta aggTheil$
BarleyLG	0.008*** (0.003)		0.040*** (0.010)	0.031*** (0.010)
Boulder clay		3.077*** (0.246)		
Region FE	Y	Y	Y	Y
Geography	Y	Y	Y	Y
Observations	1605	1605	1605	1605
R-Square	0.29	0.38	0.23	0.25
KP F-statistic			156.30	156.30

Geography controls include the natural logarithm of the parish area, the distance to Copenhagen, distance to the coast and the latitude and longitude of the parish. Regions are defined as: Greater Copenhagen, Zealand, Funen, and Jutland. Robust standard errors in parentheses.
*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$.

Table A.5
IV estimation using barley suitability (FAO) and the share of parish area classified as boulder clay.

	(1) OLS $\Delta Theil$	(2) 1st stage $ln(TotalFarmHK)$	(3) 2nd stage $\Delta Theil$	(4) 2nd stage $\Delta aggTheil$
Barleysuit	0.046** (0.021)		0.208*** (0.051)	0.160*** (0.051)
Boulder clay		0.591*** (0.032)		
Region FE	Y	Y	Y	Y
Geography	Y	Y	Y	Y
Observations	1605	1605	1605	1605
R-Square	0.29	0.65	0.27	0.27
KP F-statistic			338.30	338.30

Geography controls include the natural logarithm of the parish area, the distance to Copenhagen, distance to the coast and the latitude and longitude of the parish. Regions are defined as: Greater Copenhagen, Zealand, Funen, and Jutland. Robust standard errors in parentheses.
*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$.

Table A.6
Second stage IV estimation using total *hartkorn* and the share of parish area classified as boulder clay using Conley standard errors and different cut-off points.

	(1) $\Delta Theil$ 10 km	(2) $\Delta Theil$ 25 km	(3) $\Delta Theil$ 50 km	(4) $\Delta Theil$ 100 km
ln_TotalFarmHK_hat	0.171*** (0.038)	0.171*** (0.038)	0.171*** (0.038)	0.171*** (0.039)
Region FE	Y	Y	Y	Y
Geography	Y	Y	Y	Y
Observations	1605	1605	1605	1605

Geography controls include the natural logarithm of the parish area, the distance to Copenhagen, distance to the coast and the latitude and longitude of the parish. Regions are defined as: Greater Copenhagen, Zealand, Funen, and Jutland. Robust standard errors in parentheses.
*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$.

Table A.7
OLS estimations for effects of inequality.

	(1) ln(Total Emigration)	(2) taxpayers/# farms	(3) avrg.tax/ # farms	(4) taxable income/ # farms
L.Theil	0.735*** (0.097)	1.276** (0.553)	1648.966*** (542.338)	0.311 (0.395)
Region FE	Y	Y	Y	Y
Geography	Y	Y	Y	Y
Observations	1578	1013	1013	1013
R-squared	0.32	0.14	0.19	0.07

Geography controls include the natural logarithm of the parish area, the distance to Copenhagen, distance to the coast and the latitude and longitude of the parish. Regions are defined as: Greater Copenhagen, Zealand, Funen, and Jutland. Robust standard errors in parentheses.
*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$.

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