WORKING PAPERS

Col.lecció d'Economia E19/394

Agricultural Composition and Labor Productivity

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UB Economics Working Papers 2019/394

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Abstract: Labor productivity differences between developing and developed countries are much larger in agriculture than in non-agriculture. We show that cross-country differences in agricultural composition explain a substantial part of labor productivity differences. To this end, we group agricultural products into two sectors that are differentiated only by capital intensity. As the economy develops and capital accumulates, the price of labor-intensive agricultural goods relative to capital-intensive agricultural goods increases. This price change drives a process of structural change that shifts land and farmers to the capital-intensive sector, increasing labor productivity in agriculture. We illustrate this mechanism using a multisector growth model that generates transitional dynamics consistent with patterns of structural change observed in Brazil and other developing countries, and with cross-country differences in agricultural composition and labor productivity. Finally, we show that taxes and regulations that create a misallocation of inputs within agriculture also reduce the relative labor productivity.

JEL Codes: O41, 047.

Keywords: Structural change, Agriculture labor productivity, Capital intensity.

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Acknowledgements: Financial support from the Government of Spain through grant RTI2018-093543-B-I00 and from the Central Bank of Paraguay is gratefully acknowledged. This paper has benefited from comments by participants in the 43rd Symposium of the Spanish Economic Association, the 2018 Society for Economic Dynamics meeting (Mexico), the Public Economic Theory meeting (Vietnam), the XI Workshop on Public Policy Desing (Girona) and the seminars at the Universities of Vienna and Guanajuato.

ISSN 1136-8365

1 Introduction

A recent strand of the growth literature claims that a substantial part of cross-country income differences can be explained by differences in agricultural labor productivity between developing and developed countries.[1] This claim is based on two observations. First, labor productivity differences between developed and developing countries are much larger in agriculture than in non-agriculture. Second, employment in agriculture is still large in developing countries. In particular, Lagakos and Waugh (2013) report that agricultural labor productivity in countries in the 90th percentile of the world income distribution is 45 times larger than that of countries in the 10th percentile of the distribution. In contrast, non-agricultural labor productivity is only 4 times larger in advance countries. This implies that labor productivity of agriculture relative to non-agriculture increases along the development process.

A central issue is therefore to explain the increase of the labor productivity in agriculture relative to non-agriculture along the development path. To account for this pattern, the literature has introduced misallocations of production factors (Chen, 2017; Gottlieb and Grobovsek, 2015; Hayashi and Prescott, 2008; Restuccia et al., 2008; Restuccia and Santaeulalia-Llopis, 2017), differences in farm sizes (Adamopoulos and Restuccia, 2014), differences in technology (Chen, 2017; Gollin et al., 2007; Manuelli and Seshadri, 2014; Yang and Zhu, 2013), selection (Lagakos and Waugh, 2013), uninsurable risk and incomplete capital markets (Donovan, 2016), and differences in the quality of capital (Caunedo and Keller, 2016).

In the literature cited above, it is argued that misallocations of production factors diminish as economies develop. This can lead to an increase in both agricultural and relative labor productivity. This process is amplified by structural change and selection. That is, as structural change takes place, farmers that leave the agricultural sector first are those endowed with lower abilities for farming. The remaining farmers are endowed with higher abilities, giving rise to higher labor productivity in this sector. In addition, as the number of farmers declines due to structural change, there is an increase in the average size of farmers that increases labor productivity in this sector. Finally, economic development and capital accumulation allow an improvement in the quality of capital and a shift from a labor intensive technology to a capital intensive one. As a result, labor productivity in agriculture increases with better capital and a more capital intensive technology.

The aforementioned literature considers an aggregate agricultural sector producing a single commodity. It disregards the fact that agricultural products are diverse, that they can be produced with different technologies, and that the consumption composition of these products can change along economic development. In this paper, we identify a process of substitution of crops associated with development, which we denote as structural change within agriculture, and study how this process contributes to explain the observed increase in the relative labor productivity.

We use the US Census of Agriculture and the Food and Agriculture Organization (FAO) datasets to group crops into two different sectors: a capital intensive and a labor inten-

[1] See Chanda and Dalgaard (2008), Cao and Birchenall (2013), Caselli (2005), Gollin et al. (2002), Gollin et al. (2013) and Gollin and Rogerson (2014), Restuccia et al. (2008) and Vollrath (2009).

sive agricultural sector. The mechanism relating changes in agricultural composition and relative productivity is as follows. As the economy develops and capital accumulates, the relative price of labor intensive crops to capital intensive crops increases. If the two crops are imperfect substitutes in preferences, the production of labor intensive crops relative to capital intensive crops declines. As a consequence, aggregate agriculture becomes more capital intensive, which reduces the amount of farmers and increases the average farm size.[2] Therefore, an increase of labor productivity in agriculture can be explained by: an increase in capital intensity, higher average farm size, and a reduction in the number of farmers.

We introduce this mechanism in a multisector overlapping generations (OLG) model, in which a continuum of individuals is born in each period. These individuals have heterogeneous agricultural skills and homogeneous ability for non-agricultural work. As in Lucas (1978), young individuals with low abilities choose to become workers, whereas individuals with high abilities become entrepreneurs. In our framework, workers are employed in non-agriculture, while entrepreneurs are farmers specialized in the production of either land or capital intensive crops. Since technologies exhibit complementarity between ability and capital, only farmers endowed with high abilities choose to produce capital intensive crops. When old, individuals are retired and consume both an agricultural and a non-agricultural good subject to a minimum consumption requirement in agriculture. The agricultural good is defined as a constant elasticity of substitution (CES) aggregate of the goods produced in the two agricultural sectors.

Young individuals accumulate capital in order to consume when old. Capital accumulation and exogenous technological progress drive economic growth which generates two different processes of structural change: between sectors and within agriculture. First, to account for structural change between sectors we consider a minimum consumption requirement. This introduces an income effect which reduces the size of agriculture and the number of farmers, as a result of economic growth. The remaining farmers have higher abilities and larger farms. This is consistent with evidence provided by Adamopoulos and Restuccia (2014), who report that the average farm size in the 20% poorest countries in the world is 34 times smaller than in the 20% richest countries. It is also consistent with Lagakos and Waugh (2013), who argue that selection amplifies labor productivity differences between sectors. Second, structural change within agriculture is explained by an increase in the price of labor intensive crops relative to capital intensive crops, which is a result of capital accumulation and differences in capital intensity. As agriculture becomes more capital intensive, labor productivity in agriculture is benefited. This second process of structural change and its relation with labor productivity in agriculture are the main contributions of this paper.

The model is calibrated to match data from Brazil and we use it to simulate the dynamic transition to the steady state.[3] Along the transition, the economy develops, capital accumulates and the price of labor intensive crops relative capital intensive crops increases. The

[2]The increase in capital intensity in agriculture relative to non-agriculture, along the process of economic development, is consistent with evidence provided by Chen (2017) and Alvarez-Cuadrado et al. (2017). In particular, Chen (2017) indicates that the capital-output ratio in agriculture is 3.2 times larger in developed countries than in developing countries, whereas it is only 2.1 times larger in non-agriculture.

[3]The transitional dynamics implied by the convergence to the steady state from an initially low capital stock is equivalent to one generated by a single technological shock that affects all sectors and drives a transition between two steady states that only differ in the level of technology.

relative price change drives a process of structural change that implies: (i) a reduction in the number of farmers, mainly in the labor intensive sector; (ii) an increase in the average farm size; (iii) an increase in the fraction of harvested land used in the capital intensive sector; and (iv) an increase in the capital intensity of the agricultural sector relative to the non-agricultural sector. Higher average farm size and agricultural capital intensity lead to higher labor productivity in agriculture relative to non-agriculture. We show that this development patterns are consistent with the patterns of structural change observed in Brazil and other developing countries during the period 1960-2014. Moreover, we show that the model accounts for 41% of the observed increase in the relative labor productivity of Brazil during this period.

In addition, we provide cross-country evidence for a large sample of countries, including developing and developed countries, supporting the patterns of development implied by our model. More precisely, the cross-country data shows a positive correlation between (i) GDP per capita and the fraction of harvested land in capital intensive agriculture, and (ii) between this fraction and relative labor productivity. We calibrate our model to match data from countries at the high end of the income distribution and introduce aggregate productivity shocks to match GDP and the fraction of land in capital intensive agriculture of countries in the remaining quartiles of the income distribution. We find that our mechanism accounts for 29% of differences in relative productivity observed between countries in the first and second quartile, and 27% of differences observed between countries in the second and third quartile.

Finally, we study the effect of inefficiencies that generate a misallocation of agricultural production inputs between agricultural sectors and, therefore, reduce relative labor productivity. We denote this form of inefficiency as misallocation of agricultural composition. First, we consider the effect on the labor productivity of different taxes. The development literature has shown that sector specific taxes that cause a wedge between wages in agriculture and non-agriculture affect the relative labor productivity. We extend this analysis by showing that taxes that modify the sectoral composition of the agricultural sector also have a significant effect on the relative labor productivity, even if these taxes do not produce a direct wedge between income in agriculture and non-agriculture. Finally, we consider a different type of inefficiency, a regulation that prevents workers from leaving the agricultural sector. This regulation benefits the labor intensive agricultural sector, by avoiding structural change within agriculture, which keeps relative labor productivity low.

This paper is related to three strands of the literature. First, it relates to the structural change literature that introduces income and price effects to explain changes in the sectoral composition of an economy (see Kongsamut et al., 2001; Ngai and Pissarides, 2007; and Guerrieri and Acemoglu, 2008). We consider price and income effects to account for structural change between broad sectors and within agriculture.

Second, it relates to the literature that studies increases in the capital intensity of agriculture relative to non-agriculture resulting from technological change (see Gollin et al., 2007 and Alvarez-Cuadrado et al., 2017). In particular, it is related to Chen (2017) who links increases in both capital intensity and average farm size to changes in technology. In contrast, in our paper the increase in capital intensity is not a consequence of technological change, but of substitution among crops. This is an important difference that affects not only the model, but the targets of calibration. In the technological change literature, the model is calibrated to match a technological adoption curve or a measure of capital intensity. Instead, we calibrate the model to account for structural change within the agricultural sector.

Finally, it relates to the literature on misallocations that studies how inefficiencies generate a misallocation of different production factors between broad economic sectors (see Hayashi and Prescott, 2008 and Restuccia et al., 2008). We contributed to this literature by showing how inefficiencies can create a misallocation of resources within agricultural sectors and how this affects relative labor productivity.

The rest of the paper is organized as follows. Section 2 shows the empirical strategy followed to construct the two agricultural subsectors. Section 3 introduces the model, while Section 4 characterizes the equilibrium. Section 5 shows the results from the simulation of the model. Section 6 introduces misallocations of production factors. Finally, Section 7 concludes.

2 Agricultural sectors

We use the US Census of Agriculture to obtain the ratio between capital and value added by crop, which is a standard measure of capital intensity.[4] Table 1 shows the value of this ratio for different years in which the census is available and for four main crop categories under the North American Industry Classification System (NAICS).[5] Although there are some important changes in capital intensity among censuses, a clear pattern emerges: the first two categories, Oilseed and grain farming and Other crop farming, have a capital intensity that, on average, is larger than 1.5, whereas the last two categories, Vegetable and melon farming and Fruit and tree nut farming, have an average ratio of about 0.5. Therefore, there is a large and persistent gap in the capital intensities across different categories of crops.

This gap remains if we consider the capital intensity of crops within categories. Table 2 shows that capital intensity, defined as the ratio between capital and production, of crops in the upper two categories is in general larger than capital intensity of any crop in the bottom two categories.[6] Given these findings, we distinguish between two types of agricultural sectors. Crops in the first two categories of Table 1 belong to capital intensive agriculture, whereas crops in the other two categories belong to labor intensive agriculture. We assume that this classification remains stable through time and across countries.

Next, we use the Food and Agriculture Organization (FAO) dataset, that provides crop level data on production, prices and area harvested for a large number of countries. We consider the period 1961-2014. Using the classification of crops obtained from the US census, we classify 94 crops in the FAO dataset in order to construct the two agricultural sectors.

[4] We compute the value added as the market value of crops excluding government payments and expenditures in fertilizers, chemicals, seeds, gasoline, utilities, supplies, maintenance and all other production expenses. Capital is defined as the value of equipment and machinery.

[5] We use census data for the following years: 1978, 1982, 1992, 1997, 2002, and 2012. The first 3 censuses use the Standard Industrial Classification system (SIC); however, we can still classify them according to cathegories following NAICS. Note also that Table 1 does not include hay, nor greenhouse and floriculture production, which are crops not considered in the FAO dataset.

[6] At crop level, the US Census of Agriculture provides data on production and capital. Therefore, we compare the ratio between capital and production, instead of capital and value added which is the standard measure of capital intensity.

This gives us the value of production, the price index and the fraction of total harvested land in each sector, for each country and time period. The classification of crops is shown in the appendix.

In Figure 1, we show cross-country empirical evidence on the relation between harvested land in capital intensive agriculture and other variables of interest. In particular, Panel (a) of Figure 1 shows a positive correlation between the fraction of harvested land in capital intensive agriculture and relative capital intensity between agriculture and non-agriculture. Relative capital intensity is available for 25 countries.[7] Although data is limited, we obtain a positive correlation that is statistically significant at 3%. This positive correlation provides indirect support to our classification of crops: economies with a larger capital intensive agricultural sector have a more capital intensive agriculture relative to the non-agricultural sector.

According to the mechanism described in the introduction, the share of capital intensive agriculture increases as the economy develops. As a consequence, the labor productivity of aggregate agriculture in relation to non-agriculture should also increase. Therefore, this mechanism implies a positive correlation in the data between: (i) the fraction of harvested land in capital intensive agriculture and GDP per capita; (ii) between this fraction and relative labor productivity; and (iii) between GDP per capita and relative productivity. Panels (b), (c) and (d) of Figure 1 illustrate these three positive correlations, using the cross-country comparable measure of relative productivity provided in Restuccia et al. (2008). This sample includes 80 countries for the year 1985. Tables 3, 4 and 5 show that these three positive correlations are statistically significant. To complete this analysis, we run a linear regression between relative labor productivity and the fraction of harvested land in capital intensive crops, using a panel data of 37 countries during the period 1961-2011.[8] The data on relative productivities does not consider PPP prices; therefore, it is not-directly comparable across countries. This justifies the introduction of country and time fixed effects in the regression. The results are displayed in Table 6, they show a positive and statistically significant correlation. We conclude that the empirical evidence available provides support to our mechanism.

In Figure 2, we provide time series evidence for selected countries. The figure shows developing countries that exhibited a process of development in which the fraction of harvested land in capital intensive crops and the relative productivity increased. Among these countries, we select Brazil to calibrate the model and perform numerical simulations.

We choose Brazil because it is a large country with a diversified agricultural sector that exhibited the classical patterns of development: an increase in capital intensity, structural change and a large increase in relative labor productivity. These patterns are displayed in Figure 3, for the period 1961-2014. The figure shows that the relative price between labor and capital intensive sectors exhibits large fluctuations and a rising trend, whereas the relative production between these two sectors declines. This evidence suggests imperfect

[7] Relative capital intensity in Figure 1 is defined as capital per worker in agriculture divided by capital per worker in non-agriculture. Capital by sector is obtained from Larson et al. (2000). It is combined with employment data from the GGDC 10-Sector Database.

[8] Data on relative labor productivity is obtained from the GGDC 10-Sector Database. We exclude 5 countries for wich data is unavailable during the entire period (Germany, Hong-Kong, Ethiopia, Mauritius and Singapore) .

substitution in consumption between agricultural goods.[9] At this point, we clarify that production is not measured in value added terms, hence, it cannot be used to calibrate the model. The figure also shows that the ratio of capital to GDP has increased and, more importantly, that Brazil has experienced two important patterns of structural change. First, structural change across sectors, which is measured by the fraction of total employment in agriculture. This fraction exhibits a major decline during this period, from 55% to 16%. Second, there is structural change within agriculture, which is measured by the fraction of total land in the labor intensive sector. It also exhibits a pronounced decline, from 30% to 10%. Finally, the relative labor productivity in Brazil has experienced a considerable increase of 27% points, from 8% to 35%. The purpose of our paper is to measure how much of this increase is explained by the patterns of structural change.

In this paper, the driver of structural change is domestic consumption demand that shifts the sectoral composition along the development process. Alternatively, another potential driver of structural change, not considered in our analysis, are exports of agricultural products. Therefore, we first show that exports are not an important driver of structural change within the agricultural sector in Brazil. To this end, Figure 4 shows the evolution of agricultural exports as percentage of production for main agricultural products in Brazil. Note that we include exports of meat, as they could indirectly drive demand for cereals and oil seeds, that is, capital intensive agricultural products. The figure shows that products with high agricultural exports are meat, cereals, fruits and oil crops. Exports of meat and cereals rise after 2000 and, therefore, the increase is posterior to the period 1960-1980, in which the land in the capital intensive sector experiences the larger increase. Exports of fruits, that corresponds to labor intensive crops in our classification, increase substantially during the period 1970 to 1984 and remain stable, or even slightly decline, after that period. The increase in exports of fruits coincides with a slight reduction in the fraction of harvested land in the capital intensive sector. Therefore, exports of fruits may explain the interruption in the process of structural change in the agricultural sector that occurs in Brazil between mid 1970 and the end of the eighties. Finally, oil crops exhibit a temporary increase during the period 1972-1977 that completely vanished after 1977. Since 1997, exports of oil crops increase steadily from 14.8% to 49.1% of production. Almost all exports of oil crops correspond to soybeans, which is an important agricultural product in Brazil.

In order to illustrate the importance of soybeans, Figure 5 shows the fraction of harvested land used in the main agricultural crops from 1961 to 2017. Clearly, the most striking development is the increase in soybeans that currently accounts for 43.1% of total harvested land. We distinguish between two sub-periods in the evolution of the fraction of harvested land in soybeans. The first sub-period is 1961-1996, in which the fraction of harvested land moves from 0.9% to 22.1%. During this period exports are low, on average 18% of total production, and they have no clear trend. In the second period, 1997-2017, land in soybeans increases from 22.1% until 43.1%. During this period exports are large, on average 40% of production, and the trend is clearly rising. The existence of this second period, in which international trade is crucial to explain the evolution of soybeans, motivates the analysis in Figure 6. In this figure, we compare the observed fraction of harvested land in labor

[9] The construction of the two agricultural sectors implies perfect substitution of crops within each agricultural sector, and imperfect substitution between goods produced in different agricultural sectors.

intensive crops with he fraction that would be obtained if we kept land in soybeans fixed at 1996 levels, that is, before the rise of exports started. From this comparison, we can observe that the effect of soybeans' exports on the process of structural change within agriculture is not particularly important when during full period.

We conclude from this analysis that, although agricultural exports contribute to explain the rise of capital intensive agriculture in Brazil, they are not the main driver of structural change. This justifies a study of Brazil in the following sections, in which we present a multisector growth model of a close economy and analyze how structural change can explain an increase in relative labor productivity.

3 Model

3.1 Individuals

The economy is populated by a continuum of individuals of mass one. Individuals live for two periods. When young, they choose the sector of activity, they work and they save buying capital and land. When old, they consume the accumulated savings. Young individuals are differentiated by their ability in agriculture, which we denote by a^i. In every generation, these abilities follow the same Pareto distribution with density function $f\left(a^i\right) = \lambda\eta^{\lambda}\left(a^i\right)^{-(1+\lambda)}$ and cumulative function $F\left(a^i\right) = 1 - \left(\eta/a^i\right)^{\lambda}$. In addition, we assume that all individuals have the same ability for non-farm work.

An individual i derives utility from consumption in the second period of his life according to the following non-homothetic utility function:

$$U_t^i = \omega \ln\left(c_{a,t+1}^i - \overline{c}\right) + (1-\omega)\ln c_{n,t+1}^i, \tag{1}$$

where $c_{a,t+1}^i$ is the consumption of agricultural goods, $c_{n,t+1}^i$ is the consumption of non-agricultural goods, $\overline{c}$ is a subsistence level of agricultural consumption, and $\omega \in (0,1)$ is the weight of agricultural consumption in the utility function. The agricultural good is defined as the following aggregate of goods produced in the capital and in the labor intensive sectors:

$$c_{a,t+1}^i = \left[\mu\left(c_{L,t+1}^i\right)^{\frac{\varepsilon-1}{\varepsilon}} + (1-\mu)\left(c_{K,t+1}^i\right)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{2}$$

where $\mu \in (0,1)$ is the weight of labor intensive goods, and $\varepsilon > 0$ is the elasticity of substitution between the consumption of labor intensive agricultural goods, c_L^i, and capital intensive agricultural goods, c_K^i.

Let total consumption expenditure be defined as

$$E_{t+1}^i \equiv P_{n,t+1}c_{n,t+1}^i + P_{L,t+1}c_{L,t+1}^i + P_{K,t+1}c_{K,t+1}^i, \tag{3}$$

where $P_{L,t+1}$ is the price of the labor intensive goods, $P_{K,t+1}$ is the price of the capital intensive goods and $P_{n,t+1} = 1$ for all t, since the output of the non-agricultural sector is assumed to be the numeraire. The following individuals' consumption demands can be obtained from maximizing utility subject to (3) (derivation in Appendix A):

$$c^i_{L,t+1} = \omega\mu^\varepsilon \left(\frac{P_{L,t+1}}{P_{a,t+1}}\right)^{1-\varepsilon} \frac{E^i_{t+1}}{P_{L,t+1}} + (1-\omega)\,\mu^\varepsilon \left(\frac{P_{L,t+1}}{P_{a,t+1}}\right)^{-\varepsilon} \bar{c}, \tag{4}$$

$$c^i_{K,t+1} = \omega\,(1-\mu)^\varepsilon \left(\frac{P_{K,t+1}}{P_{a,t+1}}\right)^{1-\varepsilon} \frac{E^i_{t+1}}{P_{K,t+1}} + (1-\omega)\,(1-\mu)^\varepsilon \left(\frac{P_{K,t+1}}{P_{a,t+1}}\right)^{-\varepsilon} \bar{c}, \tag{5}$$

$$c^i_{n,t+1} = (1-\omega)\,E^i_{t+1} - (1-\omega)\,P_{a,t+1}\bar{c}, \tag{6}$$

where

$$P_{a,t+1} \equiv \left(\mu^\varepsilon P^{1-\varepsilon}_{L,t+1} + (1-\mu)^\varepsilon P^{1-\varepsilon}_{K,t+1}\right)^{\frac{1}{1-\varepsilon}}. \tag{7}$$

3.2 Technology

We distinguish between three production sectors: two agricultural and one non-agricultural. Firms in the non-agricultural sector produce combining capital and labor according to the following constant returns to scale production function:

$$Y_{n,t} = A_n K^{\alpha_n}_{n,t} N^{1-\alpha_n}_{n,t}, \tag{8}$$

where $Y_{n,t}$ is output in non-agriculture, A_n is a productivity parameter, $K_{n,t}$ is the capital stock employed in this sector, $N_{n,t}$ is the total amount of labor employed in this sector and $\alpha_n \in (0,1)$ is the capital-output elasticity. We assume that capital completely depreciates after one period. We also assume perfect competition and, hence, the wage and the rental price of capital satisfy

$$w_t = (1-\alpha_n)\,A_n K^{\alpha_n}_{n,t} N^{-\alpha_n}_{n,t}, \tag{9}$$

and

$$R_t = \alpha_n A_n K^{\alpha_n - 1}_{n,t} N^{1-\alpha_n}_{n,t}. \tag{10}$$

As capital completely depreciates, the rental price of capital satisfies $R_t = 1 + r_t$, where r_t is the interest rate. Finally, it will be useful for our analysis to rewrite (9) and (10) as follows:

$$w_t = \alpha_n^{\frac{\alpha_n}{1-\alpha_n}}\,(1-\alpha_n)\,A_n^{\frac{1}{1-\alpha_n}}\,R_t^{\frac{\alpha_n}{\alpha_n-1}} \tag{11}$$

Individuals working in agriculture are the owners of the farms. Farmers can produce either labor or capital intensive crops using the following technology:

$$y^i_{s,t} = A_s a^i \left(L^i_{s,t}\right)^{\beta_s} \left(K^i_{s,t}\right)^{\alpha_s}, \tag{12}$$

where $y^i_{s,t}$ is the output produced by a farmer with ability a^i in the agricultural sector s, A_s is the productivity parameter, $L^i_{s,t}$ and $K^i_{s,t}$ are the amount of land and capital that a farmer with ability a^i rents, $\beta_s \in (0,1)$ measures the land output elasticity and $\alpha_s \in (0,1)$ measures the capital output elasticity. The subindex s equals L when we consider the labor intensive agricultural sector and K when we consider the capital intensive sector.

We assume that $\beta_s + \alpha_s < 1$, hence, the production function exhibits decreasing returns to scale and farmers make positive profits that can be interpreted as the labor income of the farmer. Profit is given by

$$\pi^i_{s,t} = (1-\tau)\,P_{s,t} y^i_{s,t} - x_t L^i_{s,t} - (1+\kappa)\,R_t K^i_{s,t}, \tag{13}$$

where x_t is the rental cost of land, $\tau \in (0,1)$ is a tax on agricultural production and $\kappa > 0$ is a tax on the rental cost of capital used in the agricultural sector. These two taxes amount for different agricultural specific inefficiencies that reduce relative labor productivity, as we will discuss in Section 6. The farmers' optimal demands of land and capital are

$$L^i_{s,t} = \left[\left(\frac{\alpha_s}{(1+\kappa)R_t}\right)^{\alpha_s}\left(\frac{\beta_s}{x_t}\right)^{1-\alpha_s}(1-\tau)P_{s,t}A_s a^i\right]^{\frac{1}{1-\beta_s-\alpha_s}}, \tag{14}$$

$$K^i_{s,t} = \left[\left(\frac{\alpha_s}{(1+\kappa)R_t}\right)^{1-\beta_s}\left(\frac{\beta_s}{x_t}\right)^{\beta_s}(1-\tau)P_{s,t}A_s a^i\right]^{\frac{1}{1-\beta_s-\alpha_s}}, \tag{15}$$

and the amount produced is

$$y^i_{s,t} = A_s a^i\left[\left(\frac{\alpha_s}{(1+\kappa)R_t}\right)^{\alpha_s}\left(\frac{\beta_s}{x_t}\right)^{\beta_s}\left[(1-\tau)P_{s,t}A_s a^i\right]^{\alpha_s+\beta_s}\right]^{\frac{1}{1-\beta_s-\alpha_s}}. \tag{16}$$

Note that the size of a farm, measured by $L^i_{s,t}$, increases with farmer's ability, but decreases with the cost of land. Finally, we replace (14), (15) and (16) in the profit function to obtain

$$\pi^i_{s,t}\left(a^i\right) = (1-\beta_s-\alpha_s)\left[\left(\frac{\alpha_s}{(1+\kappa)R_t}\right)^{\alpha_s}\left(\frac{\beta_s}{x_t}\right)^{\beta_s}(1-\tau)P_{s,t}A_s a^i\right]^{\frac{1}{1-\beta_s-\alpha_s}}. \tag{17}$$

We assume that $\beta_K + \alpha_K > \beta_L + \alpha_L$, which implies that the fraction of after tax value of production that the farmer obtains as income is larger in labor intensive agriculture.

3.3 Individuals' decisions

Young individuals' decision regarding the sector where they work depends on their abilities. To understand this decision, we first obtain the ability of the two marginal individuals that are indifferent between two sectors of activity. The first marginal individual is indifferent between working in non-agriculture and labor intensive agriculture. We denote by $\underline{a}_t$ the ability of this individual. This ability is obtained from solving the following equation: $\pi^i_{L,t}(\underline{a}_t) = (1-\phi)w_t$, where $\phi \in (0,1)$ is a labor income tax that workers in the non-agricultural sector must pay. We find that

$$\underline{a}_t = \left(\frac{1}{(1-\tau)P_{L,t}A_L}\right)\left(\frac{(1-\phi)w_t}{(1-\beta_L-\alpha_L)}\right)^{1-\beta_L-\alpha_L}\left(\frac{x_t}{\beta_L}\right)^{\beta_L}\left(\frac{(1+\kappa)R_t}{\alpha_L}\right)^{\alpha_L}. \tag{18}$$

We denote by $\overline{a}_t$ the ability of the second marginal individual, who is indifferent between being a farmer in land and capital intensive agriculture. This ability is obtained from solving the following equation: $\pi^i_{L,t}(\overline{a}_t) = \pi^i_{K,t}(\overline{a}_t)$. We obtain

$$\overline{a}_t = \left(\frac{1-\beta_K-\alpha_K}{1-\beta_L-\alpha_L}\right)^{\frac{(1-\beta_L-\alpha_L)(1-\beta_K-\alpha_K)}{\beta_L+\alpha_L-\beta_K-\alpha_K}} \frac{\left[\left(\frac{\alpha_K}{(1+\kappa)R_t}\right)^{\alpha_K}\left(\frac{\beta_K}{x_t}\right)^{\beta_K}(1-\tau)\,P_{K,t}A_K\right]^{\frac{1-\beta_L-\alpha_L}{\beta_L+\alpha_L-\beta_K-\alpha_K}}}{\left[\left(\frac{\alpha_L}{(1+\kappa)R_t}\right)^{\alpha_L}\left(\frac{\beta_L}{x_t}\right)^{\beta_L}(1-\tau)\,P_{L,t}A_L\right]^{\frac{1-\beta_K-\alpha_K}{\beta_L+\alpha_L-\beta_K-\alpha_K}}} \tag{19}$$

The assumption $\beta_L+\alpha_L<\beta_K+\alpha_K$ implies that the profit function of capital intensive farms as a function of abilities is stepper at $a^i=\overline{a}_t$ than that of labor intensive farms. Given that individuals maximize their labor income, it follows that we can only have both types of farms if $\overline{a}_t>\underline{a}_t$. Therefore, as shown in Figure 7, individuals with $a^i\in[\eta,\underline{a}_t]$ will be workers in the non-agricultural sector, individuals with $a^i\in[\underline{a}_t,\overline{a}_t]$ will be farmers in the labor intensive sector and individuals with $a^i\in[\overline{a}_t,\infty]$ will be farmers in the capital intensive sector. Note that if $\overline{a}_t<\underline{a}_t$ then all farmers will produce capital intensive crops. In our simulations, the condition $\overline{a}_t>\underline{a}_t$ will always be satisfied along the dynamic equilibrium.

Finally, the assumption $\beta_L+\alpha_L<\beta_K+\alpha_K$ also implies that the marginal individual satisfies $P_L y^i_{L,t}(\overline{a}_t) < P_K y^i_{K,t}(\overline{a}_t)$. Thus, there is a productivity gain when the marginal farmer moves from the labor to the capital intensive sector.

4 Equilibrium

In this section, we characterize the equilibrium of the model. To this end, we obtain aggregate consumption demand, aggregate input demands and aggregate supply of output. Regarding consumption demands, note that old individuals consume income they generated when young. It follows that young individuals save all their income by buying capital and land. Therefore, the consumption expenditure of an old individual that was a non-agricultural worker in period t is $E^{n,i}_{t+1}=R_{t+1}\left[(1-\phi)\,w_t+T^i\right]$, where T^i is a transfer from the government. The consumption expenditure of an old individual that was a labor intensive farmer is $E^{L,i}_{t+1}=R_{t+1}\left[\pi^i_{L,t}(a^i)+T^i\right]$. Similarly, the consumption expenditure of an old individual that was a capital intensive farmer is $E^{K,i}_{t+1}=R_{t+1}\left[\pi^i_{K,t}(a^i)+T^i\right]$. It follows that aggregate consumption expenditure is given by

$$E_{t+1}=\int_{\eta}^{\underline{a}_t} E^{n,i}_{t+1} f\left(a^i\right)di+\int_{\underline{a}_t}^{\overline{a}_t} E^{L,i}_{t+1} f\left(a^i\right)di+\int_{\overline{a}_t}^{\infty} E^{K,i}_{t+1} f\left(a^i\right)di. \tag{20}$$

We assume that tax revenues are returned to individuals as a transfer and the government budget constraint is balanced in each period, hence,

$$\int_{\eta}^{\infty} T^i f\left(a^i\right)di=\int_{\eta}^{\underline{a}_t}\phi w_t f\left(a^i\right)di+$$

$$\int_{\underline{a}_t}^{\overline{a}_t}\left(\tau P_{L,t}y^i_{L,t}+\kappa R_t K^i_{L,t}\right)f\left(a^i\right)di+\int_{\overline{a}_t}^{\infty}\left(\tau P_{K,t}y^i_{K,t}+\kappa R_t K^i_{K,t}\right)f\left(a^i\right)di.$$

Using the government budget constraint and (20), we obtain

$$E_{t+1} = R_{t+1} \left\{ \begin{array}{c} \alpha_n^{\frac{\alpha_n}{1-\alpha_n}} (1-\alpha_n) A_n^{\frac{1}{1-\alpha_n}} R_t^{\frac{\alpha_n}{\alpha_n-1}} \left[1 - (\eta/\underline{a}_t)^\lambda\right] \\ + \left(\frac{1}{1-\tau} - \beta_L - \frac{\alpha_L}{1+\kappa}\right) \left[\left(\frac{\alpha_L}{(1+\kappa)R_t}\right)^{\alpha_L} \left(\frac{\beta_L}{x_t}\right)^{\beta_L} (1-\tau) P_{L,t} A_L\right]^{\frac{1}{1-\beta_L-\alpha_L}} \Delta_{L,t} \\ + \left(\frac{1}{1-\tau} - \beta_K - \frac{\alpha_K}{1+\kappa}\right) \left[\left(\frac{\alpha_K}{(1+\kappa)R_t}\right)^{\alpha_K} \left(\frac{\beta_K}{x_t}\right)^{\beta_K} [(1-\tau) P_{K,t} A_K]\right]^{\frac{1}{1-\beta_K-\alpha_K}} \Delta_{K,t} \end{array} \right\}, \tag{21}$$

where $\Delta_{L,t}$ and $\Delta_{K,t}$ are both positive only when $\lambda > 1/(1-\beta_K-\alpha_K)$ (derivation in Appendix B). We assume this condition in the numerical exercises below.

Given that the utility function in the model belongs to the class of Gorman preferences, the aggregate demand of the different consumption goods does not depend on the distribution of consumption expenditures, but on aggregate consumption expenditure only. Using (4), (5) and (6), we obtain aggregate consumption of labor and capital intensive agricultural goods and of non-agricultural goods that, respectively, are given by

$$C_{L,t+1} = \omega\mu^\varepsilon \left(\frac{P_{L,t+1}}{P_{a,t+1}}\right)^{1-\varepsilon} \frac{E_{t+1}}{P_{L,t+1}} + (1-\omega)\mu^\varepsilon \left(\frac{P_{a,t+1}}{P_{L,t+1}}\right)^\varepsilon \bar{c}, \tag{22}$$

$$C_{K,t+1} = \omega(1-\mu)^\varepsilon \left(\frac{P_{K,t+1}}{P_{a,t+1}}\right)^{1-\varepsilon} \frac{E_{t+1}}{P_{K,t+1}} + (1-\omega)(1-\mu)^\varepsilon \left(\frac{P_{a,t+1}}{P_{K,t+1}}\right)^\varepsilon \bar{c}, \tag{23}$$

$$C_{n,t+1} = (1-\omega) E_{t+1} - (1-\omega) P_{a,t+1}\bar{c}. \tag{24}$$

Using (14) and (15), we obtain the following aggregate demands of land and capital in each agricultural sector:[10]

$$L_{s,t} = \left[\left(\frac{\alpha_s}{(1+\kappa)R_t}\right)^{\alpha_s} \left(\frac{\beta_s}{x_t}\right)^{1-\alpha_s} (1-\tau) P_{s,t} A_s\right]^{\frac{1}{1-\beta_s-\alpha_s}} \Delta_{s,t}, \tag{25}$$

and

$$K_{s,t} = \left[\left(\frac{\alpha_s}{(1+\kappa)R_t}\right)^{1-\beta_s} \left(\frac{\beta_s}{x_t}\right)^{\beta_s} (1-\tau) P_{s,t} A_s\right]^{\frac{1}{1-\beta_s-\alpha_s}} \Delta_{s,t}, \tag{26}$$

We use (10) to obtain the demand of capital in the non-agricultural sector:

$$K_{n,t} = \left(\frac{\alpha_n A_n}{R_t}\right)^{\frac{1}{1-\alpha_n}} N_{n,t}, \tag{27}$$

where the amount of workers in this sector is given by $N_n = F(\underline{a}) = 1 - \eta^\lambda \underline{a}^{-\lambda}$. The total stock of capital, K, satisfies

$$K_t = K_{L,t} + K_{K,t} + K_{n,t}. \tag{28}$$

[10]Equation (25) is obtained following a procedure similar to the one in Appendix B and taking into account that for the labor intensive sector $L_{L,t} = \int_{\underline{a}_t}^{\overline{a}_t} L^i_{L,t} f(a^i)\, di$, whereas for the capital intensive sector $L_{K,t} = \int_{\overline{a}_t}^{\infty} L^i_{K,t} f(a^i)\, di$. Similarly, in equation (26) we take into account that $K_{L,t} = \int_{\underline{a}_t}^{\overline{a}_t} K^i_{L,t} f(a^i)\, di$ and $K_{K,t} = \int_{\overline{a}_t}^{\infty} K^i_{K,t} f(a^i)\, di$.

Finally, we use (16) to obtain aggregate production of agricultural goods in each sector[11]

$$Y_{s,t} = A_s \left[\left(\frac{\alpha_s}{(1+\kappa) R_t} \right)^{\alpha_s} \left(\frac{\beta_s}{x_t} \right)^{\beta s} \left[(1-\tau) P_{s,t} A_s \right]^{\beta_s + \alpha_s} \right]^{\frac{1}{1-\beta_s-\alpha_s}} \Delta_{s,t}. \tag{29}$$

Given an initial level of capital, an equilibrium in this economy is a path of ability thresholds $\{\underline{a}_t, \overline{a}_t\}_{t=0}^{\infty}$ that satisfies (18) and (19), a path of aggregate demands of land $\{L_{L,t}, L_{K,t}\}_{t=0}^{\infty}$ that satisfies (25), a path of aggregate demands of capital $\{K_{L,t}, K_{K,t}, K_{n,t}\}_{t=0}^{\infty}$ that satisfies (26) and (27), a path of aggregate consumption demands $\{C_{n,t}, C_{K,t}, C_{L,t}\}_{t=0}^{\infty}$ that satisfies (22), (23) and (24), a path of sectoral outputs $\{Y_{n,t}, Y_{K,t}, Y_{L,t}\}_{t=0}^{\infty}$ that satisfies (8) and (29), a path of aggregate consumption expenditure and capital $\{E_t, K_t\}_{t=0}^{\infty}$ that satisfies (21) and (28), and a path of prices $\{P_{a,t}, R_t, P_{L,t}, P_{K,t}, x_t\}_{t=0}^{\infty}$ that satisfies (7), and market clearing conditions for labor intensive agricultural goods, $C_{L,t} = Y_{L,t}$, for capital intensive agricultural goods, $C_{K,t} = Y_{K,t}$, for non-agricultural products, $Y_{n,t} = C_{n,t} + K_{t+1}$, and for land holdings $L = L_{L,t} + L_{K,t}$, where L is the fixed amount of total agricultural land.

We have not introduced the price of land explicitly. This price is obtained from arbitrage. To see this, we define the price of land as P_t and consider the fact that the income of young individuals is used to purchase land and capital. Therefore, the aggregate income of the young is equal to $P_t L + K_{t+1}$, where L and K_{t+1} are the two assets purchased by the young. The old consume the return from these assets; hence, aggregate consumption expenditures can be written as $E_{t+1} = (P_{t+1} + x_{t+1}) L + R_{t+1} K_{t+1}$. A non-arbitrage condition between the two assets, capital and land, implies that $R_{t+1} = (P_{t+1} + x_{t+1}) / P_t$. Using this condition, we can rewrite consumption expenditures as $E_{t+1} = R_{t+1} (P_t L + K_{t+1})$. From this equation, we obtain the price of land as $P_t = (E_{t+1}/R_{t+1} - K_{t+1}) L$.

5 Quantitative analysis

5.1 Calibration

The purpose of this subsection is to calibrate the parameters of the model to match the process of structural change in Brazil, both between broad sectors and within agriculture, relative capital intensities and the average farm size. The parameter values and the targets of calibration are summarized in Table 7. The calibration strategy is as follows.

First, we assume that technologies are identical across countries. Therefore, we set the value of the technological parameters using data from US. In particular, the value of α_n is obtained from the capital income share in the non-agricultural sector reported in Valentinyi and Herrendorf (2008). The technological parameters of the agricultural sector α_L, α_K, β_L and β_K, are jointly set to match the following four targets of the US economy: (i) capital intensity of labor intensive agriculture relative to capital intensity of capital intensive agriculture; (ii) land intensity of labor intensive agriculture relative to land intensity of capital intensive agriculture; (iii) capital income share in agriculture; and (iv) land income

[11] In the derivation of equation (29) we take into account that $Y_{L,t} = \int_{\underline{a}_t}^{\overline{a}_t} Y_{L,t}^i f(a^i)\, di$ and $Y_{K,t} = \int_{\overline{a}_t}^{\infty} Y_{K,t}^i f(a^i)\, di$.

share in agriculture.[12] Relative capital intensity and relative land intensity between the two agricultural sectors are obtained from the US census of agriculture in 2012, while capital and land income shares are obtained from Valentinyi and Herrendorf (2008).

Second, taxes κ and τ are set to match the relative capital intensity in Brazil, which is equal to

$$\frac{K_{L,t}+K_{K,t}}{P_{L,t}Y_{L,t}+P_{K,t}Y_{K,t}} \Big/ \frac{K_{n,t}}{Y_{n,t}} = \left(\frac{1-\tau}{1+\kappa}\right)\left(\frac{\alpha_L}{\alpha_n}\frac{P_L Y_L}{P_K Y_K + P_L Y_L} + \frac{\alpha_K}{\alpha_n}\frac{P_K Y_K}{P_K Y_K + P_L Y_L}\right). \tag{30}$$

Note that both taxes reduce relative capital intensity. We set $\kappa = 0$ and $\tau = 0.259$ to match the value of the relative capital intensity in Brazil in 2009. We also set the values of the efficiency parameters, A_n, A_K and A_L to obtain price indexes that satisfy $P_L = P_K = 1$ in 2010, the final year in the simulation.

Third, preference parameters μ and ε are set to match the value of the fraction of harvested land in labor intensive agriculture in 1960 and 2010, while preference parameters ω and $\bar{c}$ are set to match the long-run value of the share of employment in agriculture and the value of this share in 2010. The value of employment share in agriculture in 1960, 59%, is matched by setting the initial capital stock at 10% of its steady state value. Therefore, the preference parameters and the initial capital stock are jointly calibrated to explain the process of structural change in Brazil. It is important to note that the calibrated value of ε is larger than one, implying that the two agricultural sectors are gross substitutes.

Fourth, the total amount of land L and the parameter λ of the Pareto distribution are set to match two features of the distribution of farms in Brazil in 1996: (i) the average farm size and (ii) the median of the distribution of farms sizes. In Brazil, 50% of farms are smaller than 10 hectares.

Fifth, the tax ϕ is set to match the relative productivity of Brazil in 2010. This tax introduces a wedge between wages in agriculture and non-agriculture. In particular, it implies that the average wage in the agricultural sector is 21% of the average wage in the non-agricultural sector. This figure is close to that of Restuccia et al. (2008), who report wage differential figures of 38.5% in the US and much lower in developing countries.

Finally, the transition is generated by an exogenous TFP growth process. During the period considered, productivity increases in all sectors at a constant annual growth rate, γ, of 1%. The values of A_n, A_K and A_L in Table 7 correspond to the value of the sectoral TFPs in the last year of the period analyzed. This sectoral unbiased process of structural change matches the growth rate of per capita GDP in Brazil during the period 1970-2014.[13]

The calibration targets the process of structural change, the average farm size and the relative capital intensities between sectors. Our purpose is to use this calibration to analyze if the model explains the increase in relative labor productivity shown in Figure 3. This analysis is addressed in the following subsection.

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[12] Capital intensity of labor intensive agriculture relative to capital intensity of capital intensive agriculture is equal to α_L/α_K. Land intensity of labor intensive agriculture relative to land intensity of capital intensive agriculture is equal to β_L/β_K. Land income share in agriculture is equal to $(\beta_L P_L Y_L + \beta_K P_K Y_K)\,/\,(P_K Y_K + P_L Y_L) = 0.18$ and capital income share in agriculture is equal to $(\alpha_L P_L Y_L + \alpha_K P_K Y_K)\,/\,(P_K Y_K + P_L Y_L) = 0.36$.

[13] The growth rate is obtained from per capita real GDP at constant national prices. To obtain the growth rate we filter GDP per capita using the Hodrick-Prescott filter.

5.2 Structural change and labor productivity

Figure 8 summarizes the transitional dynamics of the calibrated economy. Panel (a) shows the process of structural change from the agriculture to non-agriculture, which is driven by an income effect due to the introduction of a minimum consumption requirement. Taking into account that each period is about 20 years, the simulation matches the structural transformation of Brazil during 1961-2014, displayed in Figure 3.

The decline of the agricultural employment share implies an increase in the average farm size. This is shown in Panel (b), where the average farm size is decomposed by agricultural sector. The panel shows large differences in average farm sizes between agricultural sectors. These differences are explained by capital intensive farmers having higher abilities and by complementarity between capital and land in production. They also imply that the rapid increase in average farm size in aggregate agriculture is mostly explained by the shift of farmers from labor to capital intensive agriculture.

The process of structural change within agriculture is a result of the evolution of the relative price between the two agricultural sectors, displayed in Panel (c). The accumulation of capital benefits the capital intensive agricultural sector more and, as a consequence, the price of labor intensive crops relative capital intensive crops increases. This relative price increase generates a process of structural change from labor to capital intensive agriculture when these sectors are imperfect substitutes, that is, when the calibrated elasticity of substitution is larger than one. This process of structural change is illustrated in Panels (d) and (e) of Figure 8. Panel (d) shows the process of structural change in terms of land shares, while Panel (e) in terms of the fraction of farmers in labor intensive agriculture.

The aforementioned process of structural change explains the increase in capital intensity in agriculture relative to non-agriculture shown in Panel (g). In fact, this increase is entirely driven by structural change. Too see this, we can use equation (30), where relative capital intensity between agriculture and non-agriculture is expressed as the weighted average of relative capital intensities between agricultural sectors and non-agriculture, with weights denoted as the fraction of value added generated in each agricultural sector. Given that the technologies are Cobb-Douglas, the relative capital intensity between each agricultural sector and non-agriculture is constant along the development process, as shown in Panel (f). Therefore, the increase in the capital intensity of aggregate agriculture relative to non-agriculture is driven entirely by the increase in the fraction of agricultural value added generated in the capital intensive sector.

The last panel in Figure 8 shows the increase of the labor productivity in agriculture relative to non-agriculture. Relative labor productivity increases from 24% to 35%, whereas in the data displayed in Figure 3 it increases from 8% to 35%.[14] Therefore, our model explains 41% of the observed increase in relative productivity. This is the result of the combination of three forces associated to economic development: selection, the increase in average farm size and the increase of agricultural capital intensity. On one hand, a reduction in the number of farmers implies that farmers remaining in agriculture have higher abilities and manage more land. As in Lagakos and Waugh (2013) and Adamopoulos and Restuccia (2014) both effects increase productivity in agriculture. On the other hand, the increase in

[14] Labor productivity is measured at constant prices and the magnitude of the increase in the relative productivity depends on base year. In the simulation, we consider as a base year the initial period.

productivity is also explained by an increase in relative capital intensity that results from the process of structural change within agriculture.

The contribution of this paper is to identify the process of structural change in agriculture. If agricultural composition is not considered, the model cannot account for the increase in relative capital intensity and implies a substantially smaller increase in agricultural labor productivity. This is illustrated in Panel (h) that shows labor productivities of each agricultural sector relative to labor productivity in non-agriculture. There are large and increasing differences between relative labor productivities in both agricultural sectors. Therefore, the rise of relative labor productivity shown in Panel (i) is explained by farmers moving to the more productive agricultural sector.

In order to see how structural change within the agricultural sector explains the increase in labor productivity, in Figure 9 we compare the calibrated economy, in which $\varepsilon = 4.5$, with two counterfactual economies, in which $\varepsilon = 1$ and $\varepsilon = 0.5$. In the counterfactual economies, we reset the values of $\bar{c}$ and of μ in order to match the initial sectoral composition measured by the fraction of workers in agriculture and by the fraction of harvested land in labor intensive agriculture.[15] Therefore, the three economies are initially identical and all differences during the transition are due to different processes of structural change that result from a differences in the elasticity of substitution. More precisely, in the three economies, the price of labor intensive crops relative to capital intensive crops increases due to capital accumulation. However, while the relative price increase reduces the fraction of harvested land in labor intensive agriculture under imperfect substitution ($\varepsilon = 4.5$), it has no effect on sectoral composition when the elasticity of substitution is equal to one ($\varepsilon = 1$) and has the opposite effect when the two agricultural sectors are complements ($\varepsilon = 0.5$). These different patterns are illustrated in Panels (d) and (e) of Figure 9.

Note that the process of structural change within agriculture determines the dynamics of relative capital intensity in Panel (f). It remains constant in the absence of structural change within agriculture, it increases in the benchmark economy where farmers move to the capital intensive sector, and it decreases in the economy where farmers move to the labor intensive sectors. Obviously, these different dynamics of capital intensity affect relative labor productivity negatively in the counterfactual economies. As a consequence, the reduction in the number of farmers and the increase in the average farm size are limited in the counterfactuals, as shown in the first two panels of Figure 9. Since average farm size and relative capital intensity are negatively affected by less substitution, relative labor productivity is additionally harmed. In fact, labor productivity increases only in the benchmark economy, whereas it is almost constant in the economy with $\varepsilon = 1$ and it slightly decreases in the economy with $\varepsilon = 0.5$. In contrast, relative labor productivities in each agricultural sector follow the same trends, as shown in Panels (g) and (h). Therefore, the differences in relative labor productivity are driven by changes in the composition of the agricultural sector. We conclude that introducing this process of structural change is crucial to explain the increase in relative labor productivity in Brazil.

[15] In the economy with $\varepsilon = 1$, we set $\bar{c} = 0.021669$ and $\mu = 0.763$, and in the economy with $\varepsilon = 0.5$,we set $\bar{c} = 0.025484$ and $\mu = 0.9387$.

5.3 Cross-country labor productivity differences

In the previous section we study the evolution of relative productivity along the dynamic transition of a country. In this subsection, we use the model to explain cross-country differences in labor productivity. Panel (a) of Table 8 summarizes the cross-country data. The table groups the data for 80 countries, contained in Figure 1, according to income quartiles. For each quartile, it provides median values of 4 variables of interest: GDP per capita, fraction of land in capital intensive agriculture, fraction of employment in agriculture and of relative labor productivity between agriculture and non-agricultre.[16] In the lower quartiles of income we observe a smaller fraction of land in the capital intensive sector, a larger share of employment in agriculture and a smaller relative labor productivity than in countries belonging to higher quartiles.

In this subsection, we analyze how much of these cross-country differences can be explained by our model. To this end, we calibrate the model to match the value of the variables in the highest quartile of the income distribution and set the value of relative prices, P_L and P_K, to one. The value of GDP in the other quartiles are obtained by reducing the TFP of each sector in the same proportion.[17]

The results of the simulation are shown in Panel (b) of Table 8. The model is calibrated to fully account for cross-country differences in the fraction of land in capital intensive agriculture. The model explains 29% of the differences in relative productivity between countries in the first and second quartile, and 27% of differences in relative productivity between countries in the second and third quartiles. In contrast, it explains only 12% of the differences between countries in the two highest quartiles. Therefore, our mechanism explains a larger fraction of relative labor productivity differences when we consider less developed countries. Overall our mechanism explains 17% of the cross-country differences in relative labor productivity.

Notice that our simulation exercise explains only a small fraction of the large differences in the share of employment in agriculture observed in the data. For this reason, the simulation is unable to account for a larger fraction of productivity differences across-countries. However, it is important to note the simulation exercises excludes differences between countries in sectoral productivity that could generate larger differences in both the employment share and the relative productivity. It also excludes cross-country differences in taxes that could result in misallocations that could further contribute to explaining the differences observed in relative labor productivity. These differences in taxes are considered in the following section.

[16] The data on GDP and relative labor productivity is obtained from Restuccia et al. (2008) and the data on agricultural employment and fraction of land in the capital intensive sector from the FAO database. All data refers to the year 1985. We compute the median to minimize the effect of outliers.

[17] We use the calibration of Brazil shown in Table 7 and recalibrate the following parameters $\bar{c} = 0.0051$, $\mu = 0.5449$, $\phi = 0.8536$, $\varepsilon = 2.1$, $A_K = 0.1099$ and $A_L = 0.1515$, to match $P_K = P_L = 1$ and GDP, L_K, N_a, and relative productivity in the highest quartile. To match the value of GDP in the third, second, and first quartile, we reduce all the sectoral TFPs by factor of 0.5754, 0.3651, 0.2164, respectively.

6 Misallocation of agricultural composition

In this paper, low agricultural labor productivity is explained by less capital stock or lower technology. In contrast, a large part of the literature argues that misallocations of production factors are important to explain low productivity in agriculture. Following this literature, in this section we consider the effect of a permanent increase in the tax rate on the cost of capital in agriculture, κ. Changes in this parameter allow us to compare economies with different cost of capital. The development literature has shown that development is associated with a reduction in the cost of capital. In particular, Banerjee (2001), Banerjee and Duflo (2005), Banerjee and Moll (2010) and Karlan (2013) provide evidence showing that the cost of capital is substantially larger in developing countries, specially in agriculture. Therefore, we ask if a permanent reduction in the cost of capital in agriculture can lead to an increase in relative labor productivity.

Figure 10 illustrates the effect of a permanent increase in κ by comparing the calibrated economy, in which $\kappa = 0$, with an economy in which $\kappa = 1$. First, an increase in this tax impoverishes the economy, which causes an income effect that enlarges the agricultural sector and reduces average farm size. These changes are shown in Panels (a) and (b). Panel (c) shows that the relative price of labor to capital intensive crops is lower in the economy with $\kappa = 1$. The price is lower in the initial period because the increase in the cost of the capital is larger in capital intensive agriculture after the tax is introduced, while the reduction that follows is explained by less capital accumulation.

The reduction in the relative price affects agricultural composition. In Panels (d) and (e) it is shown that the fraction of both harvested land and farmers in labor intensive agriculture increase. As a consequence, the agricultural sector as a whole becomes more labor intensive. It is important to note that this effect is increasing during the transition. In the initial period, the fraction of land in labor intensive agriculture increases by about 25%, whereas the increase is 56% in the final period.

Panel (f) shows that capital intensity in agriculture relative to non-agriculture declines after increasing κ. Since κ is a tax on capital in agriculture, it directly reduces capital intensity in both agricultural sectors. The change in agricultural composition, to labor intensive agriculture, causes an additional reduction in the capital intensity of aggregate agriculture.

Finally, the last three panels of Figure 10 illustrate the effect of an increase in κ on the relative labor productivity of each agricultural sector and aggregate agriculture. The most striking result is that an increase in the cost of capital has a positive effect on the relative productivity of each agricultural sector, but a negative and sizable effect on the relative productivity in aggregate agriculture. To explain this result, we combine (9) and the condition defining the marginal worker $\underline{a}_t$ to rewrite the labor productivity in labor intensive agriculture in relation to non-agriculture as

$$\frac{P_{L,t}Y_{L,t}}{N_{L,t}} \Big/ \frac{Y_{n,t}}{N_{n,t}} = \frac{P_{L,t}Y_{L,t}}{N_{L,t}} \Big/ \frac{\pi^{i}_{L,t}\left(\underline{a}_t\right)}{\left(1-\alpha_n\right)\left(1-\phi\right)}.$$

We next use (17) and (29) to obtain

$$\frac{P_{L,t}Y_{L,t}}{N_{L,t}}\bigg/\frac{Y_{n,t}}{N_{n,t}}=\frac{\Delta_{L,t}}{\underline{a}_t^{\frac{1}{1-\beta_s-\alpha_s}}N_{L,t}}\left(\frac{1-\alpha_n}{1-\beta_L-\alpha_L}\right)\left(\frac{1-\phi}{1-\tau}\right).$$

Finally, using the expression of $\Delta_{L,t}$ and the fact that $N_{L,t}=F\left(\overline{a}_t\right)-F\left(\underline{a}_t\right)$, we obtain

$$\frac{P_{L,t}Y_{L,t}}{N_{L,t}}\bigg/\frac{Y_{n,t}}{N_{n,t}}=\left(\frac{\lambda}{\lambda-\frac{1}{1-\beta_L-\alpha_L}}\right)\left(\frac{1-\alpha_n}{1-\beta_L-\alpha_L}\right)\left(\frac{1-\phi}{1-\tau}\right)\left(\frac{1-\left(\frac{\overline{a}_t}{\underline{a}_t}\right)^{\frac{1}{1-\beta_L-\alpha_L}-\lambda}}{1-\left(\frac{\overline{a}_t}{\underline{a}_t}\right)^{-\lambda}}\right). \quad (31)$$

We follow a similar procedure, using (9) and (29), to rewrite the relative labor productivity in the capital intensive sector as

$$\frac{P_{K,t}Y_{K,t}}{N_{K,t}}\bigg/\frac{Y_{n,t}}{N_{n,t}}=\frac{\left[\left(\frac{\alpha_K}{(1+\kappa)R_t}\right)^{\alpha_K}\left(\frac{\beta_K}{x_t}\right)^{\beta_K}(1-\tau)\,P_{K,t}A_K\right]^{\frac{1}{1-\beta_K-\alpha_K}}\Delta_{K,t}}{N_{K,t}}\frac{(1-\alpha_n)(1-\phi)}{(1-\tau)\,\pi^i_{L,t}\left(\underline{a}_t\right)}.$$

We use (17), the condition defining the marginal worker $\overline{a}_t$, the expression of $\Delta_{K,t}$ and the fact that $N_{K,t}=1-F\left(\overline{a}_t\right)$, to get

$$\frac{P_{K,t}Y_{K,t}}{N_{K,t}}\bigg/\frac{Y_{n,t}}{N_{n,t}}=\left(\frac{\lambda}{\lambda-\frac{1}{1-\beta_K-\alpha_K}}\right)\left(\frac{1-\alpha_n}{1-\beta_K-\alpha_K}\right)\left(\frac{1-\phi}{1-\tau}\right)\left(\frac{\overline{a}_t}{\underline{a}_t}\right)^{\frac{1}{1-\beta_L-\alpha_L}}. \quad (32)$$

From (31) and (32), it is obvious that κ has no direct effect on the relative labor productivity in this sectors. It only has an indirect effect through selection, since it affects marginal abilities of farmers in each production sector, as it can be seen in (18) and (19). The intuition is quite immediate. An increase in κ reduces the amount of farmers in the capital intensive sector ($\overline{a}_t$ increases). The remaining farmers have higher abilities, which explains the increase in the relative productivity of the capital intensive sector. In the labor intensive sector, the number of farmers increases as the economy is poorer. On one hand, low ability individuals enter this sector ($\underline{a}_t$ declines), reducing relative productivity. On the other hand, high ability individuals enter this sector too ($\overline{a}_t$ increases), increasing relative productivity. The second effect predominates in this calibration, which explains the increase in relative productivity. It follows that relative productivities are affected by κ indirectly, through changes in the abilities of the farmers. However, as the numerical simulations illustrate, this effect is small.

In order to explain the positive and large effect of κ on relative productivity of aggregate agriculture, we rewrite relative productivity as

$$\frac{P_{L,t}Y_{L,t}+P_{K,t}Y_{K,t}}{N_{L,t}+N_{K,t}}\bigg/\frac{Y_{n,t}}{N_{n,t}}=\left(\frac{P_{L,t}Y_{L,t}}{N_{L,t}}\bigg/\frac{Y_{n,t}}{N_{n,t}}\right)\frac{N_{L,t}}{N_{a,t}}+\left(\frac{P_{K,t}Y_{K,t}}{N_{K,t}}\bigg/\frac{Y_{n,t}}{N_{n,t}}\right)\frac{N_{K,t}}{N_{a,t}} \quad (33)$$

An increase in κ shifts agricultural composition towards the labor intensive sector, which is the sector with lower relative labor productive. Therefore, the increase in κ reduces relative labor productivity of aggregate agriculture. Note also that the effect of a permanent increase in κ is initially small and increasing along the transition. This is a consequence of the effect of κ on the sectoral composition, which is also increasing along the transition.

We show that κ affects relative productivity through changes in the agricultural composition in Figure 11. In this case, we consider the effect of a permanent increase in κ when $\varepsilon = 1$. From this exercise, we observe that the increase in κ reduces the relative price and the relative capital intensity. However, the price change does not affect agricultural composition (panels (d) and (e) in Figure 11) and, as a consequence, the effect on relative labor productivity of aggregate agriculture is negligible.[18]

As we discuss in the introduction, the literature that introduces misallocations to account for cross-country differences in relative productivity, between broad sectors, considers a unique agricultural sector. In this literature, taxes create a wedge between agriculture and non-agriculture that directly affects relative productivity (Restuccia et al., 2008 and Chen, 2017). In our paper, these taxes are given by ϕ or τ. It follows from (31) and (32) that they directly affect relative productivity. Our contribution to this literature is to show that taxes that do not create this direct wedge between the agriculture and non-agriculture can also affect relative productivity, through agricultural composition. Therefore, in our model, a reduction in the cost of capital, κ, provides an alternative explanation to differences in relative labor productivity, across countries and time.

The misallocation literature studies different regulations that limit mobility of workers across sectors or land acquisition. These regulations directly affect the optimal allocation of inputs, mainly in the agricultural sector, which reduces productivity. We show how this type of regulation can affect agricultural composition thus introducing another channel through which relative labor productivity is altered. This is illustrated in Figure 12, where we compare the calibration of Brazil with an economy subject to an extreme labor mobility restriction that prevents workers from moving out of agriculture. This type of restriction is similar to the one introduced in Hayashi and Precott (2008). In this counterfactual economy, the number of farmers remains constant at the level of the initial period. This restriction has three effects. First, it prevents any increase in average farm size, which affects productivity in agriculture negatively, as in Adamopoulos and Restuccia (2014). Second, since the number of farmers is now larger, labor intensive agriculture is benefited. This explains the decline in relative prices. As a consequence, farmers and land remain employed in the labor intensive sector. Third, the abundance of farmers and the absence of structural change deter capital accumulation in the agricultural sector. Therefore, relative capital intensity declines. The conjunction of these three effects explains the decline in relative labor productivity. As follows from (33), the reduction in the relative labor productivity is explained by both a reduction in relative productivity in each agricultural sector (see Panels (g) and (h)) and by a process of structural change towards labor intensive agriculture. Therefore, the mechanism introduced in this paper can be seen as complementary to the ones in the misallocation literature in explaining differences in relative labor productivity.

[18] The increase in κ impoverishes the economy and as result the number of farmers increases ($\underline{a}_t$ declines). Given that the fraction of workers remains constant when $\varepsilon = 1$, $\overline{a}_t$ also declines. This implies that, in this calibration, farmers with lower ability produce capital intensive crops, which explains the reduction in the relative productivtiy of this sector.

7 Concluding remarks

Differences in labor productivity between developed and developing countries are substantially larger in agriculture than in non-agriculture. Since agricultural employment is large in developing countries, the development literature has concluded that explaining these large differences in agricultural productivity is central to understanding cross-country income differences. We contribute to this literature by showing that the agricultural composition can explain a significant part of low agricultural productivity observed in developing countries.

We use data from the US census of agriculture and FAO to group agricultural products into two agricultural sectors that differ only in the capital intensity of the production function. These data is used to calibrate a multisector growth model. We use the model to show that, as the economy develops and capital becomes abundant, the price of labor intensive agriculture relative to capital intensive agriculture increases. This relative price change drives a process of structural change within agriculture that implies: (i) a reduction in the number of farmers, mainly in the labor intensive sector; (ii) an increase in the average farm size; (iii) an increase in the fraction of harvested land used in the capital intensive sector; and (iv) an increase in the capital intensity of the agricultural sector relative to the non-agricultural sector. Since farms are larger and more capital intensive, labor productivity in agriculture increases relative to non-agriculture. We show that these development patterns, implied by our model, are consistent with time series evidence for Brazil and other developing countries, and a cross-country sample that includes developing and developed countries.

In the counterfactual simulations, we show that when structural change within agriculture is limited, by either low substitution of crops in preferences or misallocations of production factors, relative labor productivity is negatively affected.

We use the mechanisms of our model to study how misallocations affect relative labor productivity. To this end, we distinguish between two types of inefficiencies: taxes and regulations. From the development literature, we know that taxes produce a direct wedge between income in agriculture and non-agriculture that affects relative labor productivity. We extend this analysis and show that taxes can affect relative labor productivity indirectly, by altering the composition of agriculture, even without the direct wedge between income in agriculture and non-agriculture. Regarding regulations, we showcase how a policy that limits the mobility of individuals out agriculture misallocates resources within agriculture and reduces the relative labor productivity. In sum, we show that misallocations of factors across agricultural sectors, resulting from different forms of inefficiencies, can have a negative impact on relative labor productivity.

Finally, throughout this paper, we maintain that the force that drives the process of sectoral composition within agriculture is economic development and capital accumulation. However, we acknowledge that exports of agricultural products could be another potential source of structural change. In the case of Brazil, we have shown that agricultural exports are an important factor since 2000, but trade alone is unlikely to explain the in change agricultural composition observed during the entire period considered.

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A Consumers' problem

The consumer chooses c_L, c_K and c_n to maximize (1) subject to (2) and (3). We break this problem in two steps. First, consumers choose c_L^i and c_K^i to maximize (2) subject to

$$E_{a,t+1}^i = P_{L,t+1}c_{L,t+1}^i + P_{K,t+1}c_{K,t+1}^i,$$

where $E_{a,t+1}^i$ is the agricultural expenditure of individual i. Maximization implies

$$c_{L,t+1}^i = \mu^\varepsilon \left(\frac{P_{L,t+1}}{P_{a,t+1}}\right)^{1-\varepsilon} \frac{E_{a,t+1}}{P_{L,t+1}}, \tag{34}$$

$$c_{K,t+1}^i = (1-\mu)^\varepsilon \left(\frac{P_{K,t+1}}{P_{a,t+1}}\right)^{1-\varepsilon} \frac{E_{a,t+1}}{P_{K,t+1}}, \tag{35}$$

where

$$P_{a,t+1} \equiv [\mu^\varepsilon P_{L,t+1}^{1-\varepsilon} + (1-\mu)^\varepsilon P_{K,t+1}^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}}.$$

Note that this price satisfies

$$P_{a,t+1}c_{a,t+1}^i \equiv E_{a,t+1}^i = P_{L,t+1}c_{L,t+1}^i + P_{K,t+1}c_{K,t+1}^i.$$

Second, consumers choose c_a^i and c_n^i by maximizing (1) subject to

$$E_{t+1}^i = c_{n,t+1}^i + P_{a,t+1}c_{a,t+1}^i.$$

Maximization implies equation (6) and

$$P_{a,t+1}c_{a,t+1}^i = \omega E_{t+1}^i + (1-\omega)\, P_{a,t+1}\bar{c}.$$

Combining this last equation with (34) and (35), we obtain equations (4) and (5).

B Aggregate consumption expenditures

We use (20) and (13) to obtain aggregate consumption expenditure as

$$E_{t+1} = R_{t+1}\left\{ \begin{array}{c} \int_\eta^{a_t} (1-\phi)\, w_t f(a^i)\, di + \int_{\underline{a}_t}^{\overline{a}_t} \left[(1-\tau)\, P_{L,t}y_{L,t}^i - x_t L_{L,t}^i - (1+\kappa)\, R_t K_{L,t}^i\right] f(a^i)\, di \\ + \int_{\overline{a}_t}^{\infty} \left[(1-\tau)\, P_{K,t}y_{K,t}^i - x_t L_{K,t}^i - (1+\kappa)\, R_t K_{K,t}^i\right] f(a^i)\, di + \int_\eta^\infty T^i f(a^i)\, di \end{array} \right\}.$$

We use the government budget constraint to obtain

$$E_{t+1} = R_{t+1}\left\{ \begin{array}{c} \int_\eta^{a_t} w_t f(a^i)\, di + \int_{\underline{a}_t}^{\overline{a}_t} \left[P_{L,t}y_{L,t}^i - x_t L_{L,t}^i - R_t K_{L,t}^i\right] f(a^i)\, di \\ + \int_{\overline{a}_t}^{\infty} \left[P_{K,t}y_{K,t}^i - x_t L_{K,t}^i - R_t K_{K,t}^i\right] f(a^i)\, di \end{array} \right\},$$

and using (14) and (15) we get

$$E_{t+1} = R_{t+1}\left\{ \begin{array}{c} \int_\eta^{a_t} w_t f(a^i)\, di + \left[1-(1-\tau)\,\beta_L - \left(\frac{1-\tau}{1+\kappa}\right)\alpha_L\right] \int_{\underline{a}_t}^{\overline{a}_t} P_{L,t}y_{L,t}^i f(a^i)\, di \\ + \left[1-(1-\tau)\,\beta_K - \left(\frac{1-\tau}{1+\kappa}\right)\alpha_K\right] \int_{\overline{a}_t}^{\infty} P_{K,t}y_{K,t}^i f(a^i)\, di \end{array} \right\}.$$

Using (11) and (16), the previous equation can be rewritten as equation (21) where

$$\Delta_{L,t} = \int_{\underline{a}_t}^{\bar{a}_t} \left(a^i\right)^{\frac{1}{1-\beta_L-\alpha_L}} f\left(a^i\right) = \int_{\underline{a}_t}^{\bar{a}_t} \lambda\eta^{\lambda} \left(a^i\right)^{\frac{1}{1-\beta_L-\alpha_L}-(1+\lambda)}$$

$$= \lambda\eta^{\lambda} \left(\frac{\left(\bar{a}_t\right)^{\frac{1}{1-\beta_L-\alpha_L}-\lambda} - \left(\underline{a}_t\right)^{\frac{1}{1-\beta_L-\alpha_L}-\lambda}}{\frac{1}{1-\beta_L-\alpha_L} - \lambda} \right),$$

and

$$\Delta_{K,t} = \int_{\bar{a}_t}^{\infty} \left(a^i\right)^{\frac{1}{1-\beta_K-\alpha_K}} f\left(a^i\right) di = \int_{\bar{a}_t}^{\infty} \lambda\eta^{\lambda} \left(a^i\right)^{\frac{1}{1-\beta_K-\alpha_K}-(1+\lambda)}.$$

Note that only if $\lambda > \frac{1}{1-\beta_K-\alpha_K}$ $\Delta_{K,t} > 0$ is finite and equal to

$$\Delta_{K,t} = \lambda\eta^{\lambda} \left(-\frac{\left(\bar{a}_t\right)^{\frac{1}{1-\beta_K-\alpha_K}-\lambda}}{\frac{1}{1-\beta_K-\alpha_K} - \lambda} \right).$$

The inequality $\lambda > \frac{1}{1-\beta_K-\alpha_K}$ implies that $\Delta_{K,t} > 0$. It also implies that $\lambda > \frac{1}{1-\beta_L-\alpha_L}$ and, hence, $\Delta_{L,t}$ is also positive when $\bar{a}_t > \underline{a}_t$. Therefore, we assume that $\lambda > \frac{1}{1-\beta_K-\alpha_K}$.

C List of capital and labor intensive crops:

Capital intensive crops:

Barley; Beans, dry; Beans, green; Broad beans, horse beans, dry; Buckwheat; Cashewapple; Cereals, nes; Cow peas, dry; Grain, mixed; Maize; Maize, green; Millet; Mustard seed; Oats; Oilseeds nes; Okra; Peas, dry; Poppy seed; Quinoa; Raspberries; Rice, paddy; Rye; Safflower seed; Seed cotton; Sesame seed; Sorghum; Soybeans; String beans; Sugar beet; Sugar cane; Sugar crops, nes; Sunflower seed; Sweet potatoes; Tobacco, unmanufactured; Wheat; Yams.

Land intensive crops:

Agave fibres nes; Almonds, with shell; Anise, badian, fennel, coriander; Apples; Apricots; Areca nuts; Artichokes; Asparagus; Avocados; Bambara beans; Bananas; Bastfibres, other; Berries nes; Blueberries; Brazil nuts, with shell; Cabbages and other brassicas; Canary seed; Carobs; Carrots and turnips; Cashew nuts, with shell; Cassava; Cassava leaves; Castor oil seed; Cauliflowers and broccoli; Cherries; Cherries, sour; Chestnut; Chick peas; Chicory roots; Chillies and peppers, dry; Chillies and peppers, green; Cinnamon (canella); Cloves; Cocoa, beans; Coconuts; Coffee, green; Cranberries; Cucumbers and gherkins; Currants; Dates; Eggplants (aubergines); Fibre crops nes; Figs; Flax fibre and tow; Fonio; Fruit, citrus nes; Fruit, fresh nes; Fruit, stone nes; Fruit, tropical fresh nes; Garlic; Ginger; Gooseberries; Grapefruit (inc. pomelos); Grapes; Groundnuts, with shell; Hazelnuts, with shell; Hemp tow waste; Hempseed; Hops; Jojoba seed; Jute; Kapok fruit; Karite nuts (sheanuts); Kiwi fruit; Kola nuts; Lemons and limes; Lentils; Lettuce and chicory; Linseed; Lupins; Mangoes, mangosteens, guavas; Manila fibre (abaca); Mate; Melons, other (inc.cantaloupes); Melonseed; Mushrooms and truffles; Nutmeg, mace and cardamoms; Nuts, nes; Oil palm fruit;

Olives; Onions, dry; Onions, shallots, green; Oranges; Papayas; Peaches and nectarines; Pears; Peas, green; Pepper (piper spp.); Peppermint; Persimmons; Pigeon peas; Pineapples; Pistachios; Plantains and others; Plums and sloes; Potatoes; Pulses, nes; Pumpkins, squash and gourds; Pyrethrum, dried; Quinces; Ramie; Rapeseed; Roots and tubers, nes; Rubber, natural; Sisal; Spices, nes; Spinach; Strawberries; Tallowtree seed; Tangerines, mandarins, clementines, satsumas; Taro (cocoyam); Tea; Tomatoes; Tung nuts; Vanilla; Vegetables, fresh nes; Vegetables, leguminous nes; Vetches; Walnuts, with shell; Watermelons.

D Tables and figures

Table 1: Capital intensity for main crop categories

Capital/Value added	1978	1982	1992	1997	2002	2012
Oilseed and grain	1.52	1.62	1.62	1.53	1.73	1.43
Other crop	1.28	1.19	1.10	1.21	3.92	2.55
Vegetable and melon	0.50	0.47	0.48	0.44	0.53	0.58
Fruit and tree nut	0.55	0.59	0.49	0.44	0.53	0.44

Source: US census of agriculture.

Table 2: Capital intensity

Oilseed and grain farming	0.93	Vegetable and melon farming	0.35
Soybean	1.16	Potato	0.41
Oilseed (ex soybean)	1.15	Other vegetable and melon	0.34
Dry pea and bean	0.95	Fruit and tree nut farming	0.29
Wheat	1.16	Orange groves	0.23
Corn	0.86	Citrus (ex. orange) groves	0.25
Rice	0.66	Noncitrus fruit and tree nut	0.44
Other grain	0.93	Apple orchards	0.29
Other crop farming	1.44	Grape vineyards	0.24
Tobacco	0.73	Strawberry	0.11
Cotton	0.89	Berry (except strawberry)	0.53
Sugarcane	0.40	Tree nut	0.32
All other crop	1.33	Orange groves	0.23

Source: US census of agriculture 2012. Capital intensity is defined as capital over production.

Table 3: Relative labor productivity

Dependent variable: Relative labor productivity	Coefficient
Constant	-0.0589 (0.06755)
Fraction of land in capital intensive agriculture	0.2791^{***} (0.09307)
Observations	80
Countries	80
R^2	0.1034
R^2 adjusted	0.0919

Source: Restuccia et al. (2008) and FAOstats.
***p-value < 0.01.

Table 4: GDP per capita

Dependent variable: GDP per capita	Coefficient
Constant	-288.75 (4060.54)
Fraction of land in capital intensive agriculture	15714.64^{***} (5594.536)
Observations	80
Countries	80
R^2	0.0919
R^2 adjusted	0.0802

Source: Penn World Table and FAOstats.
***p-value < 0.01.

Table 5: Relative productivity

Dependent variable: Relative productivity	Coefficient
Constant	0.0141 (0.01958)
Real GDP per capita	0.0000115^{***} ($1.37e^{-6}$)
Observations	80
Countries	80
R^2	0.4681
R^2 adjusted	0.1148

Source: Penn World Table and Restuccia et al. (2008).
***p-value < 0.01.

Table 6: Relative labor productivity

Dependent variable: Relative labor productivity	Coefficient
Constant	0.0264 (0.04137)
Fraction of land in capital intensive agriculture	0.2305^{***} (0.04905)
Country fixed effects	Yes
Time fixed effects	Yes
Observations	1802
Countries	37
R^2	0.3879
R^2 adjusted	0.3565

Source: GGDC 10-Sector Database and FAOstats.
***p-value < 0.01.

Table 7: Calibration

Parameter	Value	Target
ω	0.01	Long-run employment share in agriculture
$\bar{c}$	0.0177	Employment share in agriculture in Brazil in 2010 (17%)[a]
μ	0.4891	Fraction of land in non-capital intensive agriculture in Brazil in 1960 (30%)[b]
ε	4.498	Fraction of land in non-capital intensive agriculture in Brazil in 2010 (10%)[b]
A_n	1	Normalization
A_L	0.1775	$P_L = 1$ in 2010[b]
A_K	0.1874	$P_K = 1$ in 2010[b]
γ	1.01	Growth of real GDP per capita (2.4%)[a]
α_n	0.33	Capital income share in non-agriculture[c]
β_L	0.03	Relative land intensity between the two agricultural sectors (0.15)[d]
β_K	0.22	Land income share in agriculture (0.18)[c]
α_K	0.42	Relative capital intensity between the two agricultural sectors (0.313)[d]
α_L	0.13	Capital income share in agriculture (0.36)[c]
λ	12.63	Fraction of small farms in Brazil in 1996 (50% of farms smaller than 10 ha)[e]
η	1	Normalization
L	12.1	Average farm size in Brazil in 1996 (72 ha)[e]
ϕ	0.8245	Relative labor productivity in Brazil in 2010 (0.35)[a]
τ	0.259	Relative capital intensity in Brazil in 2009 (0.65) [f]
κ	0	Normalization

Source: (a) GGDC10-Sector Database, PWT 9.0; (b) FAO data set; (c) Valentinyi and Herrendorf (2008); (d) US census of agriculture; (e) 2000 World Agricultural Census; (f) World Input Output Database 2012.

Table 8: Cross country analysis

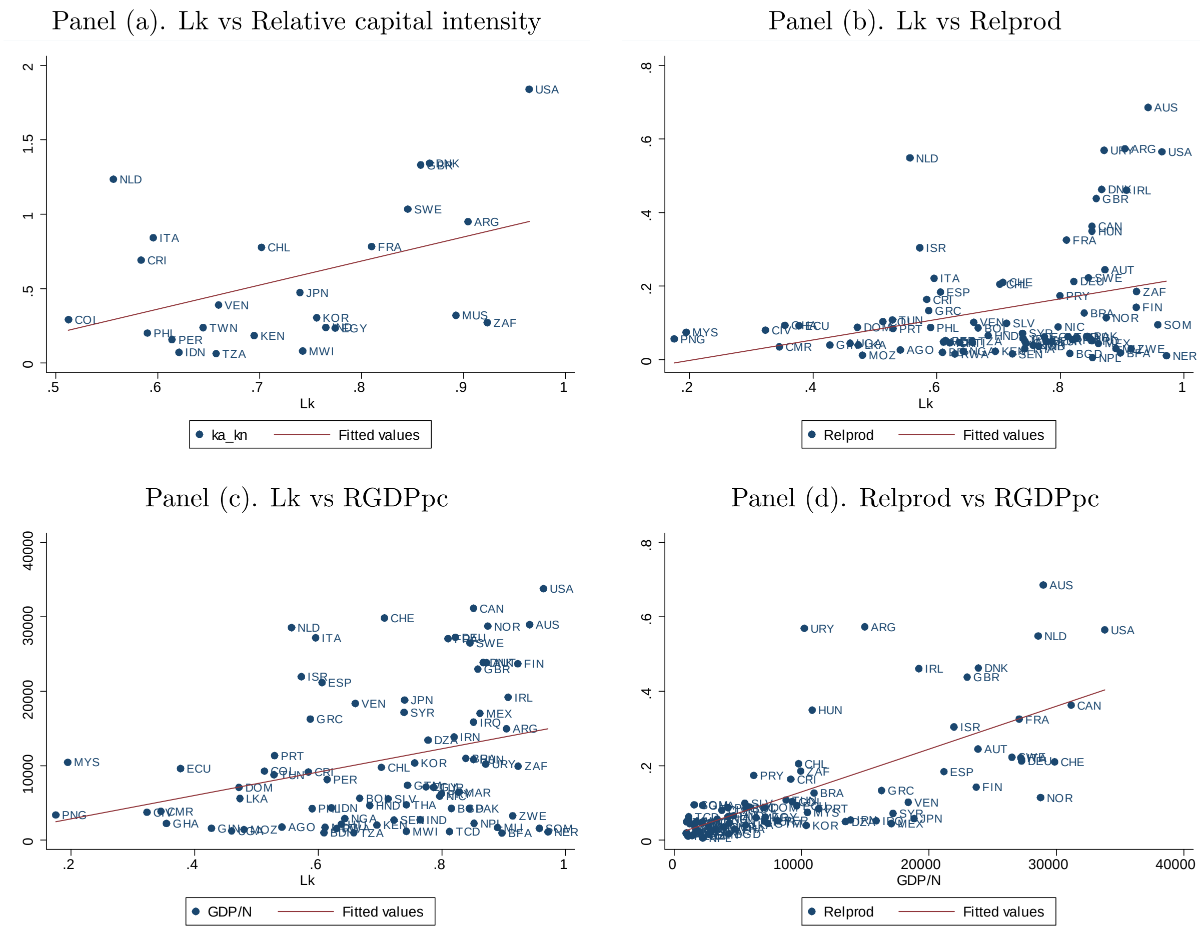
	(a) Data				(b) Model				
Quartile	GDP*	L_K	N_a	Rel Prod	GDP	L_K	N_a	Rel Prod	Δ Rel Prod**
4	1	0.83	0.06	0.23	1	0.83	0.06	0.234	12%
3	0.41	0.75	0.28	0.10	0.41	0.78	0.14	0.219	27%
2	0.18	0.69	0.53	0.06	0.18	0.73	0.28	0.209	29%
1	0.06	0.67	0.82	0.03	0.06	0.67	0.59	0.201	- -

Source: Restuccia et al. (2008), FAOstats and own elaboration.

*The GDP is relative to the highest quartile.

**Δ Rel Prod is the fraction of the change in relative productivity explained by the model.

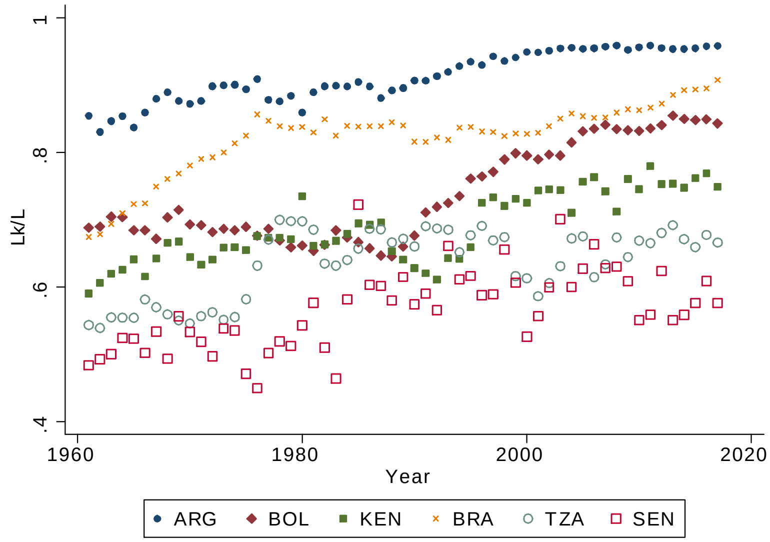
Figure 1. Cross country comparisons



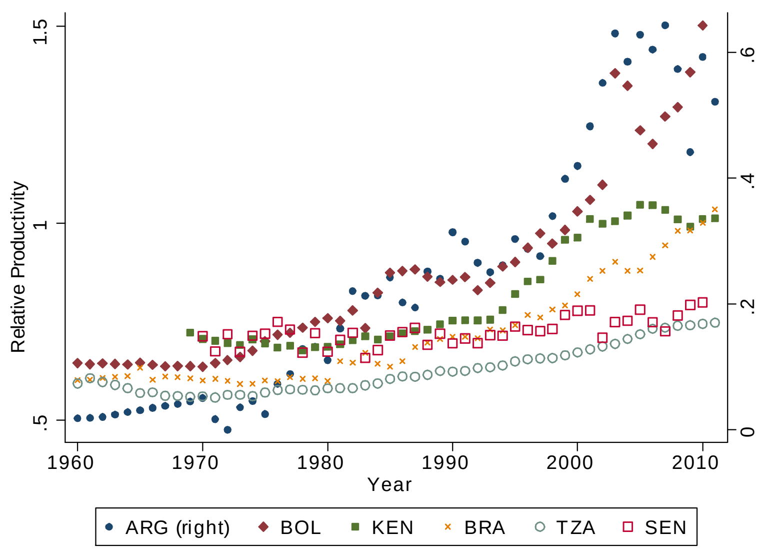
Source: Restuccia et al. (2008), Larson et al. (2000), FAOstats and GGDC 10-Sector Database. Lk , Relprod, RGDPpc indicate land in capital intensive agriculture, relative productivity between land and capital intensive agriculture and real GDP per capita, respectively.

Figure 2. Development patterns

LK/L



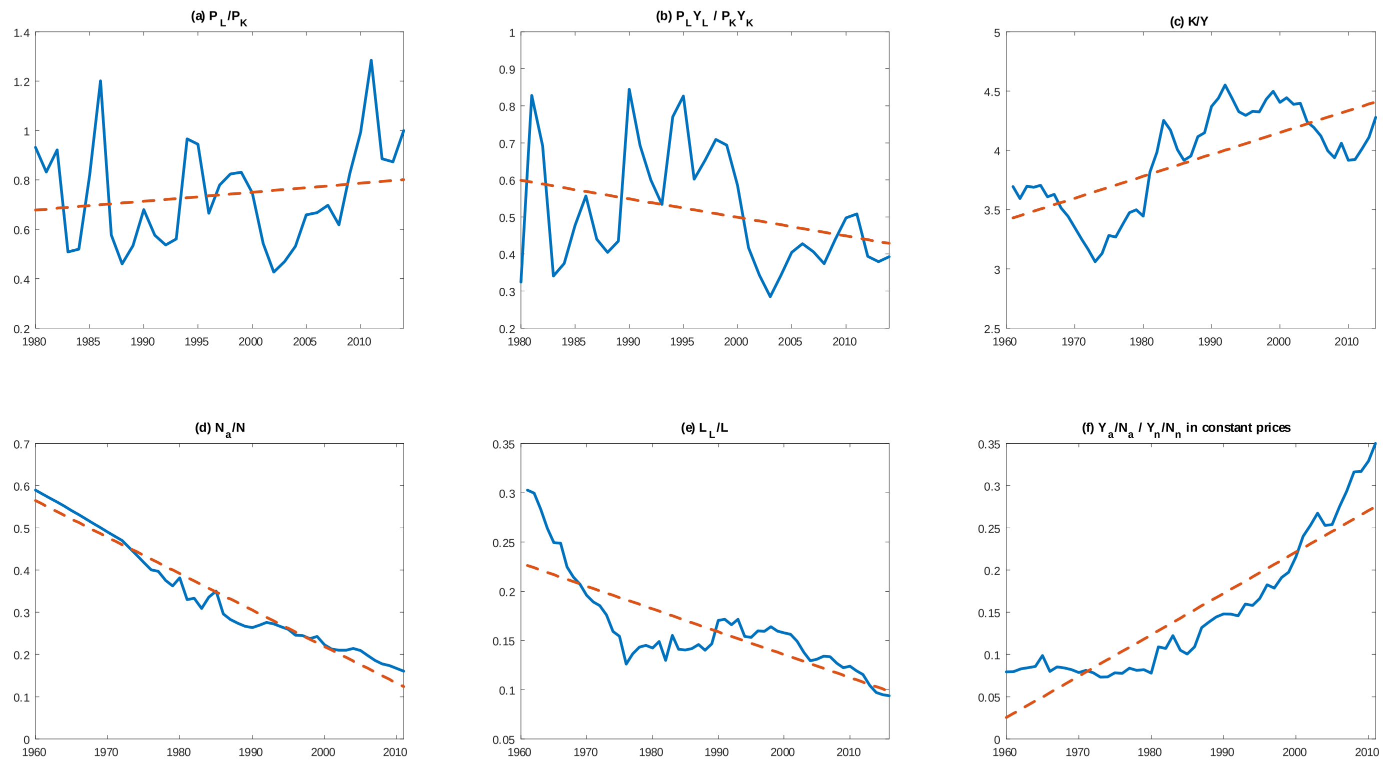
Relative productivity



Source: FAOstats and GGDC 10-Sector Database.

Countries included: Argentina, Bolivia, Kenya, Brazil, Tanzania, Senegal.

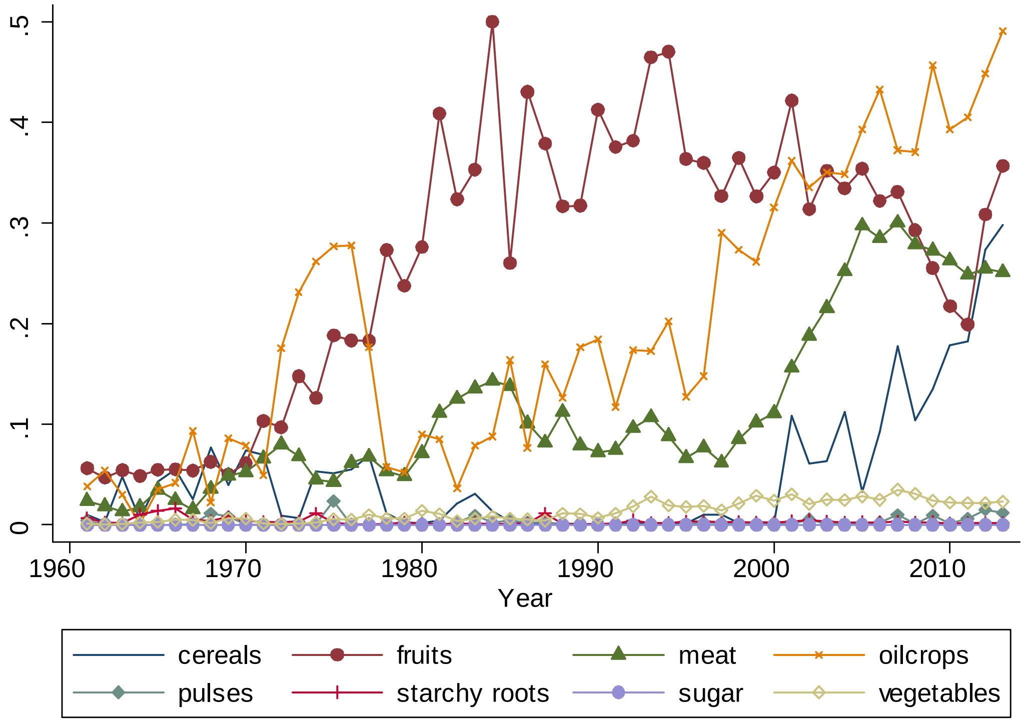
Figure 3. Development patterns of Brazil



Source: GGDC10-Sector data base, Penn World Table and FAO data base.

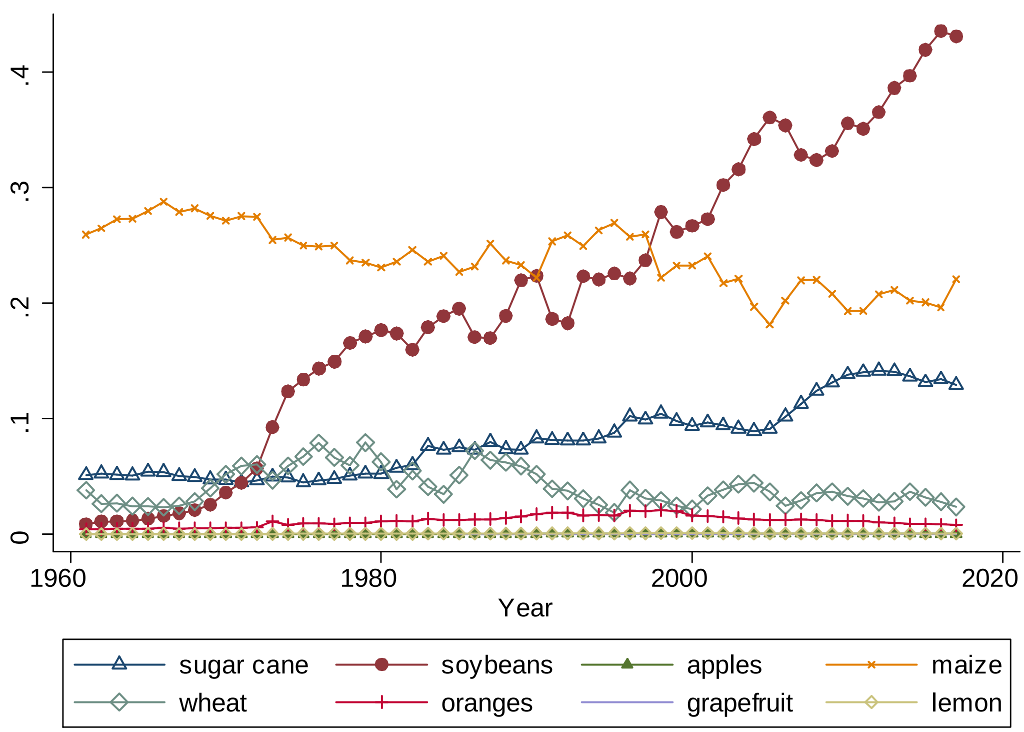
The continuous line indicates observed data, the dashed line is a linear trend. The variables P_L/P_K, N_a/N, L_L/L, Y_a/N_a and Y_n/N_n indicate relative price of labor to capital intensive agricultural goods, employment share in agriculture, land share in labor intensive crops, value added per worker in the agricultural sector, value added per worker in the non-agricultural sector, respectively. Data for P_L/P_K and P_LY_L/P_KY_K are available for 1980-2014, for N_a/N for 1960-2011, for K/Y, L_L/L and Y_a/N_a / Y_n/N_n for 1961-2014.

Figure 4. Exports as percentage of production for agricultural main categories



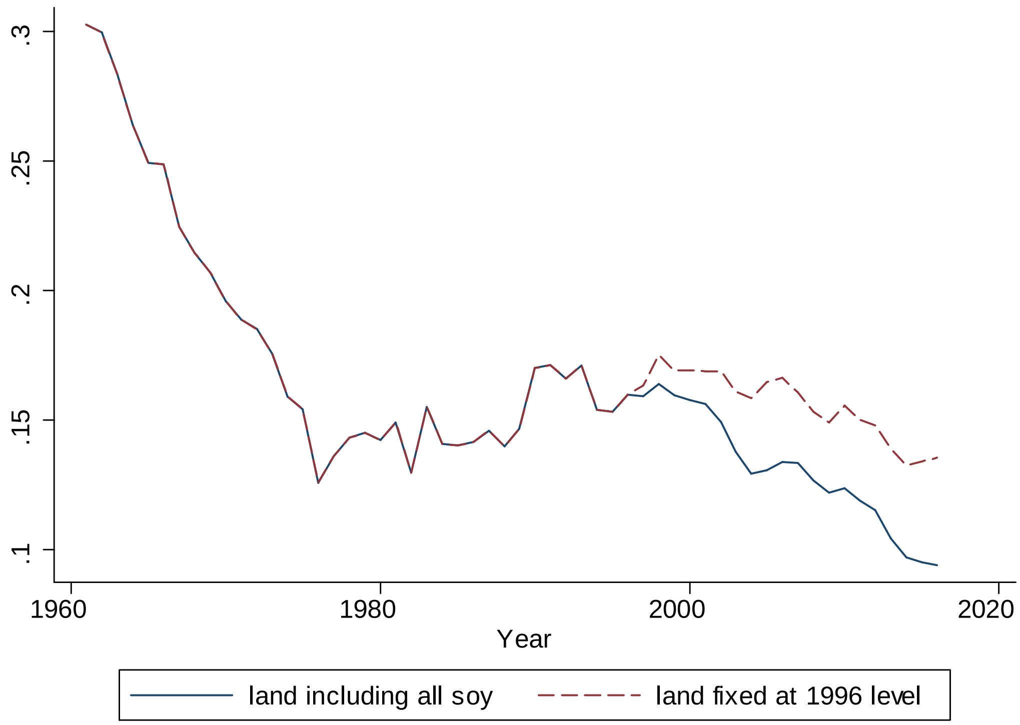
Source: FAOstats - Food Balance Sheets.

Figure 5. Fraction of harvested land by main agricultural crops



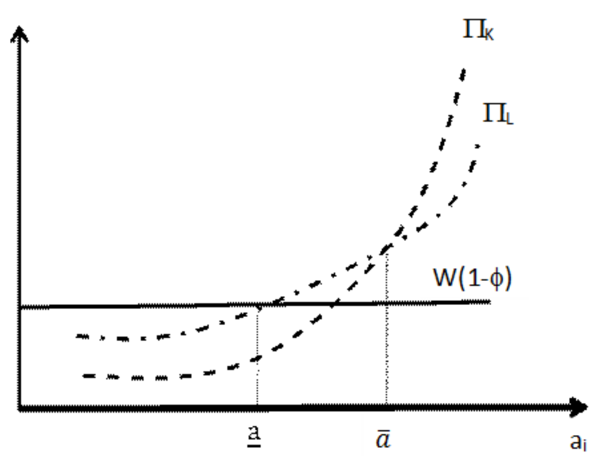
Source: FAOstats.

Figure 6. Fraction of harversted land in labor intensive crops



Source: FAOstats and own elaboration.

Figure 7. Income profile of individuals



Note: We assume that $\beta_L + \alpha_L < \beta_K + \alpha_K$

Figure 8

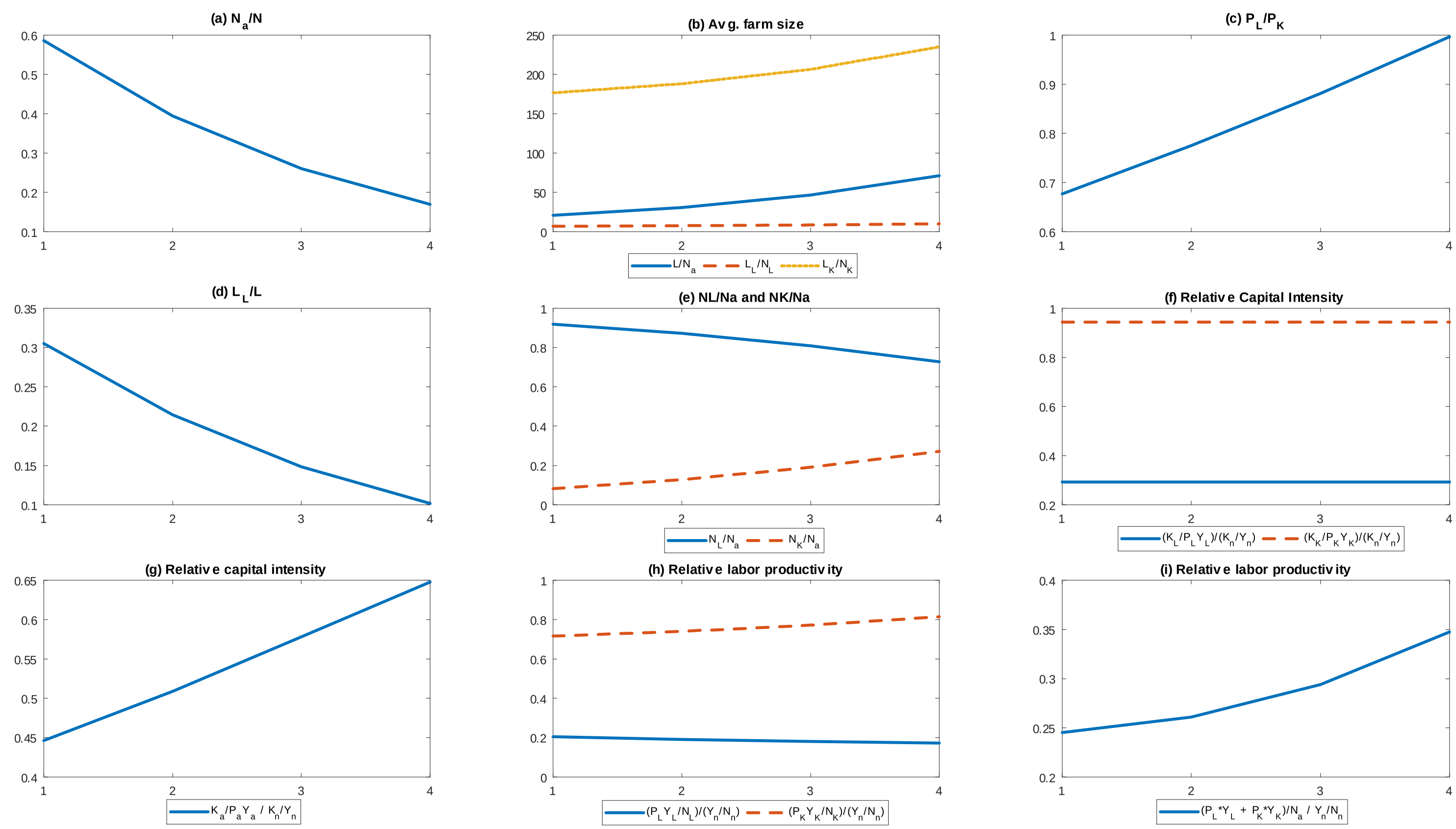
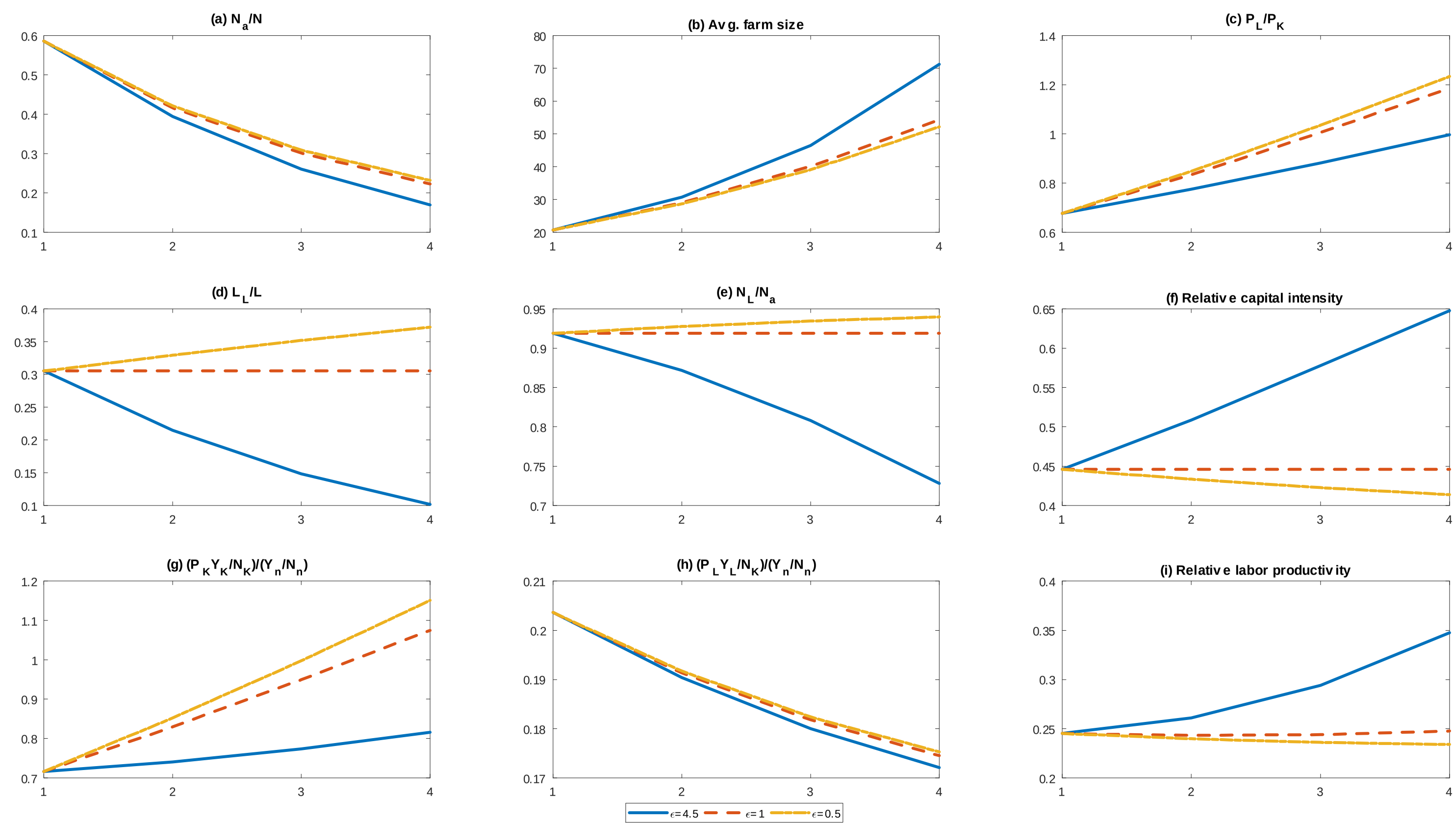
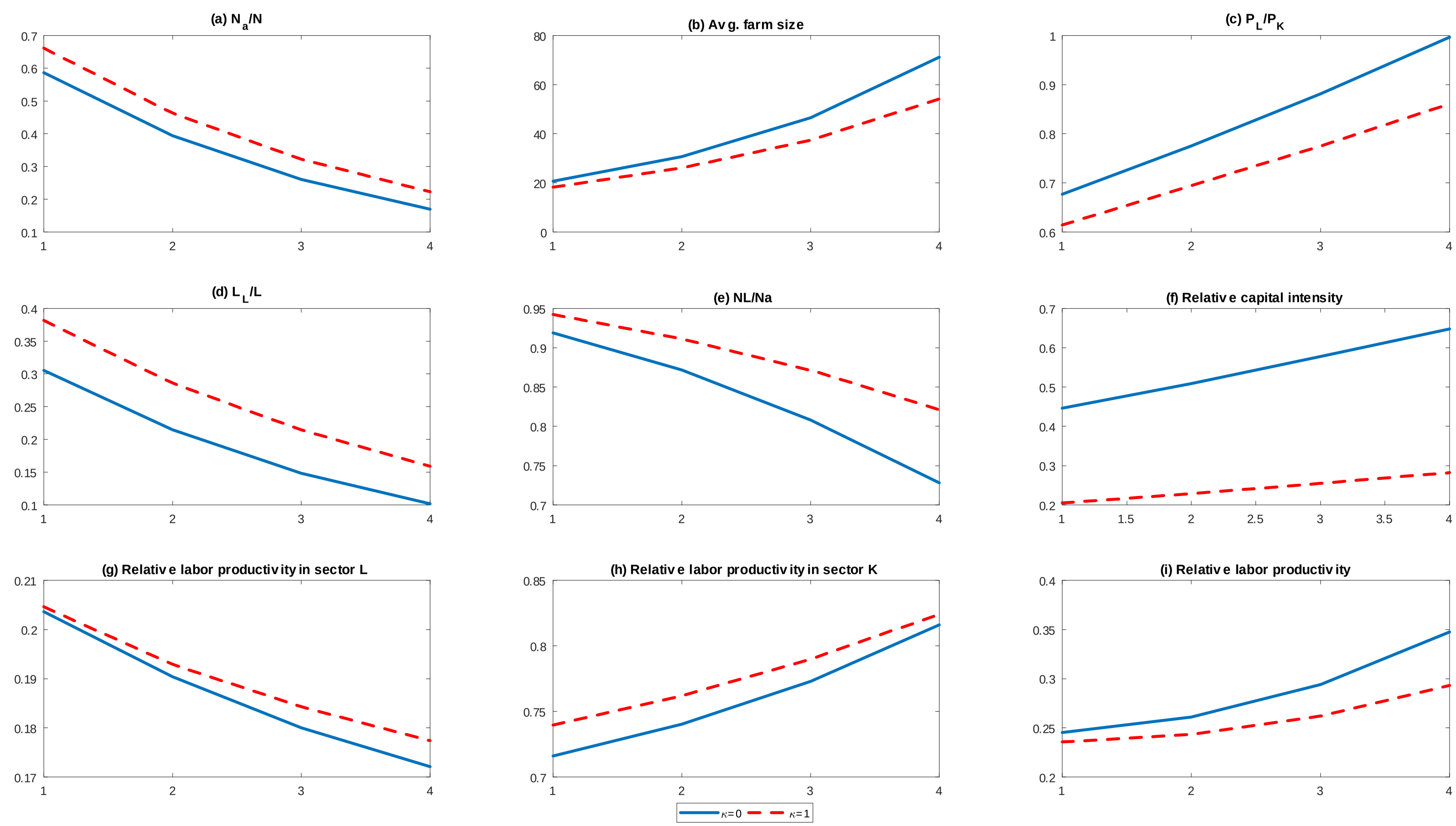

(a) N_a/N
(b) Avg. farm size
L/N_a
L_L/N_L
L_K/N_K
(c) P_L/P_K
(d) L_L/L
(e) NL/Na and NK/Na
N_L/N_a
N_K/N_a
(f) Relative Capital Intensity
(K_L/P_L Y_L)/(K_n/Y_n)
(K_K/P_K Y_K)/(K_n/Y_n)
(g) Relative capital intensity
K_a/P_a Y_a / K_n/Y_n
(h) Relative labor productivity
(P_L Y_L/N_L)/(Y_n/N_n)
(P_K Y_K/N_K)/(Y_n/N_n)
(i) Relative labor productivity
(P_L*Y_L + P_K*Y_K)/N_a / Y_n/N_n

Figure 9



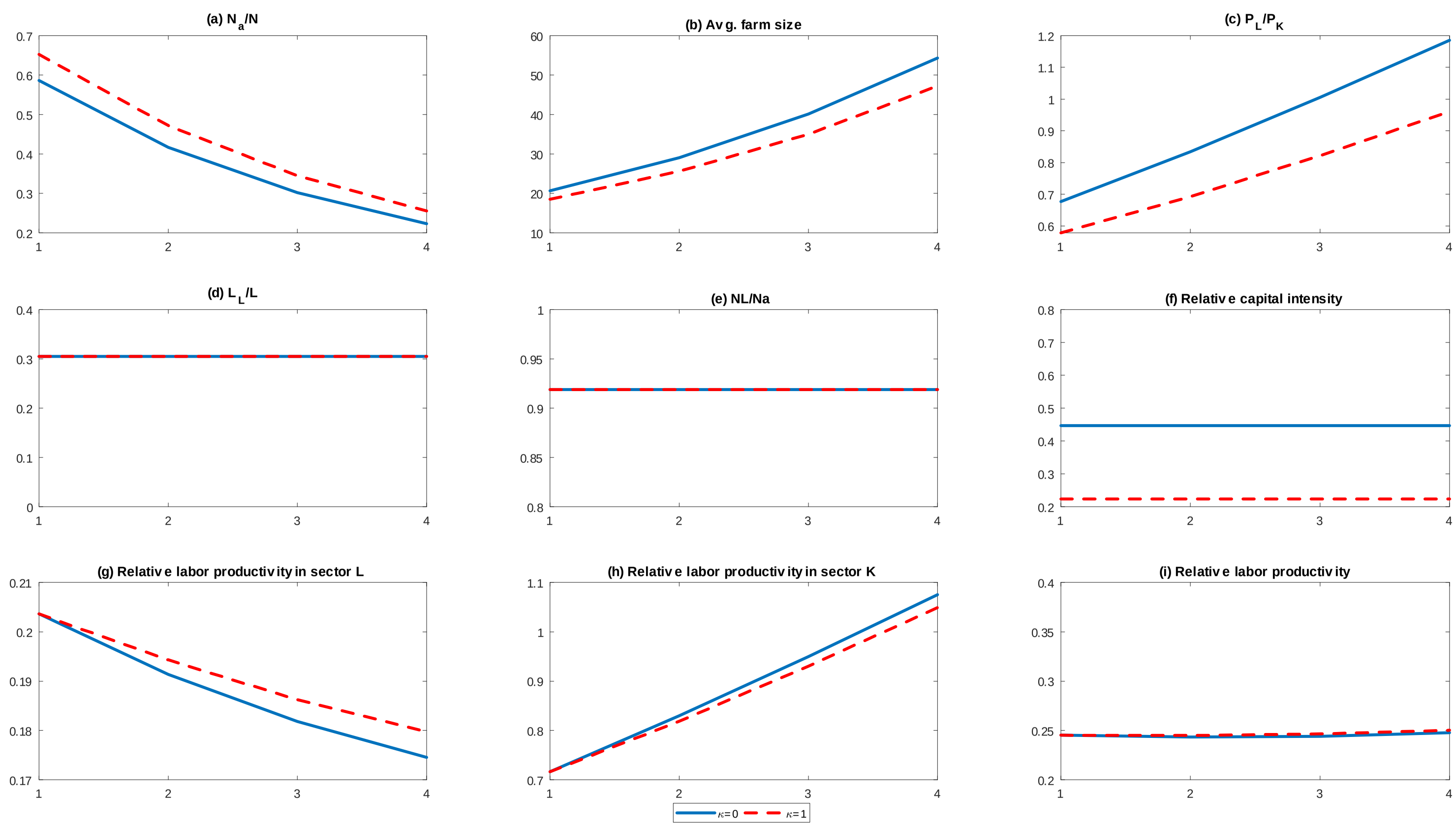
(a) N a /N
(b) Avg. farm size
(c) P L /P K
(d) L L /L
(e) N L /N a
(f) Relative capital intensity
(g) (P K Y K /N K)/(Y n /N n)
(h) (P L Y L /N K)/(Y n /N n)
(i) Relative labor productivity
ϵ=4.5
ϵ=1
ϵ=0.5

Figure 10



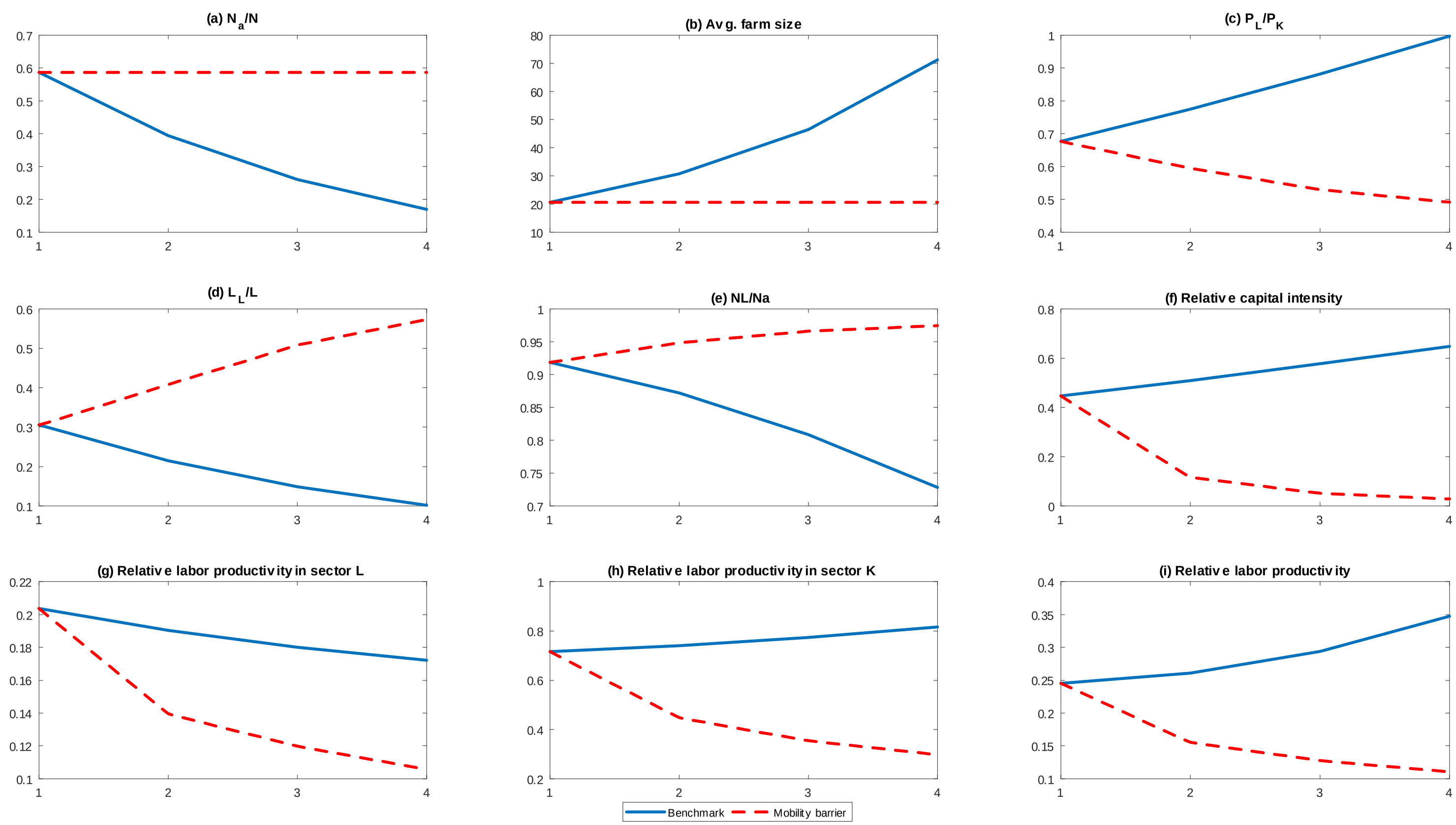
(a) N a /N
(b) Avg. farm size
(c) P L /P K
(d) L L /L
(e) NL/Na
(f) Relative capital intensity
(g) Relative labor productivity in sector L
(h) Relative labor productivity in sector K
(i) Relative labor productivity
κ=0
κ=1

Figure 11



(a) N_a/N
(b) Avg. farm size
(c) P_L/P_K
(d) L_L/L
(e) NL/Na
(f) Relative capital intensity
(g) Relative labor productivity in sector L
(h) Relative labor productivity in sector K
(i) Relative labor productivity
κ=0
κ=1

Figure 12



(a) N_a/N
(b) Avg. farm size
(c) P_L/P_K
(d) L_L/L
(e) NL/Na
(f) Relative capital intensity
(g) Relative labor productivity in sector L
(h) Relative labor productivity in sector K
(i) Relative labor productivity
Benchmark
Mobility barrier