UNIVERSITAT DE BARCELONA

Essays on Agriculture and Sectoral Composition in Developing Countries

Cesar Francisco Blanco Aguirre

PhD in Economics

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Cesar Francisco Blanco Aguirre

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Xavier Raurich

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Contents

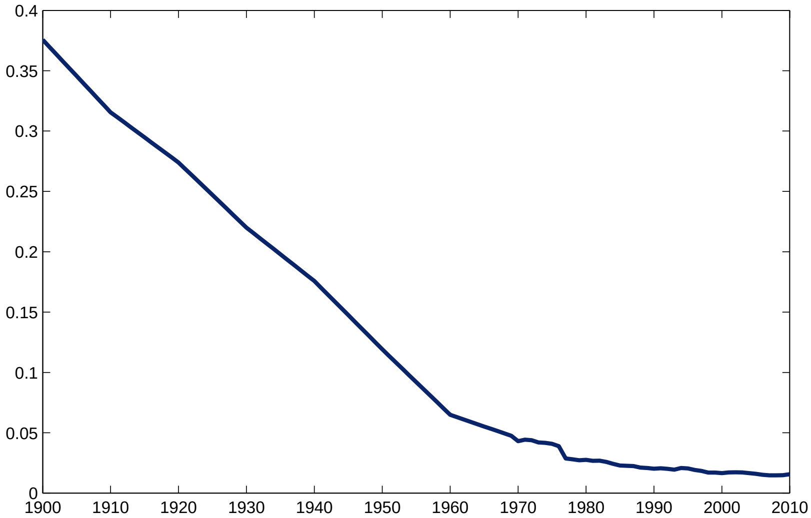
Introduction

The three chapters that follow can be regarded as independent essays. They are, however, closely related by two underlying ideas. First, that the sectoral composition of an economy, defined by broad sectors, changes as economic growth takes place. Second, that the sectoral composition of currently developing countries, where agricultural activity is predominant, is the result of circumstances specific to this set of countries and it implies consequences for economic policy. This thesis attempts to delve into some of these circumstances and consequences.

The secular relocation of economic activity from agriculture to manufacturing and later to services is known in the literature as structural change. This process has been documented by Clark (1957), Chenery (1960) and Syrquin (1988), and has been described by Kuznets (1973) as one of the main features of modern economic growth. Looking at Figure I.1, we can observe a continuous decline of agricultural employment share in U.S., from 37.5% in 1900 to 1.5% in 2010. A similar pattern can be observed in all currently advanced nations.

To account for the decline in agricultural employment, the literature relies on demand and supply factors. The demand approach to structural change is based on the Engel law, which states that income elasticity of demand for agricultural goods is lower than one. Therefore, as income expands demand for agricultural goods as percentage of aggregate demand declines, leading to a lower employment share in this sector. To account for lower-that-one income elasticity, Echevarria (1997), Laitner (2000), Kongsamut *et al.* (2001), Caseli and Coleman (2001), Foellmi and Zweimuller (2008), among others, rely on non-homothetic preferences. On the other hand, supply-side arguments are related to Baumol's (1967) cost disease. In this case, if productivity growth in agriculture is larger than in the rest of the economy, relative agricultural prices decline. This results in lower employment in this sector when there is complementarity in preferences between agricultural and non-

Figure I.1: Agricultural employment share: U.S. 1900-2010



Source: Wingerden (2014).

agricultural goods. To account for supply-side structural change, Ngai and Pissarides (2007) consider biased technical change, Acemoglu and Guerrieri (2008) consider different capital intensities across sectors and capital deepening, while Alvarez-Cuadrado *et al.* (2013) consider differences in the elasticity of capital-labor substitution across sectors. Clearly, both supply and demand-side arguments are not mutually exclusive. In fact, Buera and Kaboski (2009), Herrendorf *et al.* (2014) and Alonso-Carrera *et al.* (2017), among others, combine both mechanisms into a single model.

To account for the quantitative relevance of these mechanisms, Dennis and Iscan (2009) study long-run patterns of structural change in the U.S. during 1800-2000. They find that both income effects and productivity growth differences are important to explain observed patterns in this country. Their results suggest that, in the period before 1950, income effects are dominant in explaining the movement of employment out agriculture. In a related paper, Alvarez-Cuadrado and Poschke (2009) find that improvements in manufacturing productivity explain the reduction of agricultural employment in the period before 1920 in 12 currently industrialized countries, while improvements in agricultural technology are more important in the period after 1960. That is, improvements in manufacturing technology are more important in earlier stages of development. Interestingly, these papers find that international trade is not important for patterns of structural change in the U.S. and other industrial countries.

In developing countries, economic activity is concentrated in the agricultural sector. Lagakos and Waugh (2013) report that, whereas employment share in agriculture is only 3% in countries in the 90th percentile of the world income distribution, agricultural employment accounts for 78% of total employment in countries in the lowest 10th percentile of the distribution. From a demand-side perspective, this fact is explained by low and stagnant income. From a supply-side approach it can be explained by low agricultural productivity. When agricultural productivity is low, labor movement out of agriculture is constrained by minimum requirements of food consumption and can not be released to manufacturing. This has been described by Schultz (1953) as the "food problem".

As reported by Restuccia *et al.* (2008), the consequence of high agricultural employment share in developing countries, where labor productivity is low, is low aggregate productivity. Moreover, Gollin *et al.* (2002) argue that poor agricultural technology and policies delay industrialization, which in turn results in low income per capita. In sum, studying the causes behind low agricultural productivity in developing countries seems key to understand the process of development.

Several authors have studied the reasons behind low agricultural productivity in developing countries. For instance, Caselli and Coleman (2001) argue that declining educational costs prompted structural change out of unskilled agriculture and, as a consequence, drove regional income convergence between southern and northern states in the U.S. Hayashi and Prescott (2008) point that a labor barrier kept agricultural employment high in Japan before World War II. Dekle and Vandenbroucke (2012) asses China's recent episode of structural transformation and find that the reduction in government size accounts for 15% of the agricultural employment decline. Gollin and Rogerson (2014) find that high transportations costs across regions in Uganda explain the large share of workers in subsistence agriculture. Adamopoulos and Restuccia (2014) show that farm size distortions have an impact on agricultural and aggregate productivity. Wingender (2015) poses that elasticity of substitution between skilled and unskilled workers is higher in agriculture than in non-agriculture, therefore the agricultural productivity gap is high in countries where the share of high skill workers is low. Eberhardt and Vollrath (2016) show that differences in factor input intensities explain a significant portion of cross-country differences in agricultural productivity. Bustos *et al.* (2016) show that technical progress reallocates agricultural employment towards manufacturing depending on the factor-bias in an open economy. Donovan (2016) argues that farmers in developing countries use fewer intermediate inputs as they lack access to insurance markets.

This thesis contributes to this literature by studying not only reasons underlying high employment in agriculture, but also its consequences.

In the first chapter, we study the effect of international trade on patterns of structural change of an economy with a high concentration of exports in the agricultural sector. We argue that traditional mechanisms of structural change, under a closed economy assumption, are not able to fully account for the high concentration of employment in the agricultural sector observed in this type of economy. For this purpose, we calibrate a three-sector growth model to quantify the role of trade in explaining patterns of structural change in Paraguay. This country has experienced a significant rise in net agricultural exports as a percentage of aggregate output during the period 1962-2012. The model includes non-homothetic preferences, biased technical change, differences in capital intensity across sectors, capital accumulation and balanced international trade as sources of structural change.

The contributions are three-fold. First, we show that international trade is crucial to explain the composition of employment in a country with increasing net agricultural exports. The model including trade explains 84.7% of changes in employment shares, while the model excluding trade can only account for 36.1% of changes. Second, employment in agriculture remains large in order to satisfy foreign demand, even as the expenditure share of consumption in this sector declines. Third, in the long-run employment shifts directly from agriculture into services, bypassing manufacturing. These results indicate that patterns of structural change in agricultural exporting countries can be different from the ones observed in currently developed countries.

In the second chapter, co-authored with Sebastian Diz, we investigate the consequence for monetary policy of high concentration of economic activity in the agricultural sector. A key issue for the monetary authority is to define the measure of inflation to target. Central banks may choose to target headline inflation, the broadest measure available. Alternatively, they may target core inflation, a narrow measure excluding volatile prices of agricultural goods. It has been argued that targeting core inflation is sufficient to stabilize inflation

(Mishkin (2008)). In developing countries, however, agriculture accounts for a large share of total expenditure and, therefore, it has a large weight in headline inflation. In this chapter, we study how is the optimal measure of inflation, defined as the weight assigned to agricultural inflation that minimizes welfare loss, affected by the sectoral composition in developing economies.

To answer this question, we build a two-sector model including features from the structural change and new Keynesian literature. In the model, agricultural goods have lower-than-one income and price elasticity relative to non-agricultural goods. Regarding the new Keynesian features of the model, we consider sticky prices in non-agriculture, flexible prices in agriculture and sticky wages in both sectors. The model is calibrated to match the sectoral composition of both developing and advanced countries

The main findings of the chapter are the following. First, the optimal measure of inflation depends on the type of shock hitting the economy. After shocks to the flexible agricultural sector, it is optimal to fully target non-agricultural inflation. On the other hand, after shocks to the sticky non-agricultural sector, it is optimal to fully target agricultural inflation. We find that free labor mobility across sectors and sticky wages are important for the later result. Second, as structural change takes place, the optimal measure of inflation remains the same, but there are important implications in terms of welfare gains of targeting the appropriate measure of inflation.

In the third chapter, co-authored with Xavier Raurich, we present a novel mechanism to explain cross-country differences in agricultural productivity. We study how changes in the sectoral composition within agriculture affect agricultural employment, farm size, capital intensity in agriculture and agricultural productivity. We consider two agricultural sectors producing different goods and using production technologies that differ in the degree of capital intensity. We assume that these goods are imperfect substitutes in consumption.

Using crop level data from the Food and Agriculture Organization (FAO), we distinguish between capital and land intensive technologies. We find that, in the U.S., the relative price of land intensive crops increases, while the share of consumption and land in land intensive crops declines, suggesting imperfect substitution between these agricultural products.

We introduce a model to account for these facts and show that the process of economic growth, through capital accumulation, involves declining prices of capital intensive agricultural goods in units of land intensive products. The change in relative prices drives the reallocation of resources within agriculture, towards the capital intensive agricultural sector. This process, and the reduction of minimum consumption requirements associated with development, implies a reduction in the number of farmers, mainly in the land intensive sector, an increase in farm size, and an increase in capital intensity in agriculture. The immediate implication of this process is an increase in agricultural productivity of farmers in relation to workers in non-agriculture. We show that complementarity in preferences between agricultural goods limits agricultural productivity gains during economic growth. Finally, we show that our mechanism is complementary to labor mobility and credit constraints considered by other authors in the literature.

1 Agricultural trade and structural change: the case of Paraguay

1.1 Introduction

The shift of economic activity from agriculture to manufacturing and later to services has been described by Kuznets (1973) as one of the main characteristics of economic growth. The secular decline of employment in the agricultural sector is a robust feature of the data for currently developed countries.[1] To account for this fact, the literature relies on demand and supply factors, mostly in the context of closed economies. In developing countries, however, employment in agriculture remains comparatively large. In this chapter we argue that, in the subset of developing countries with positive net agricultural exports, international trade has an important role in explaining observed patterns of structural change.

To account for structural change patterns in the U.S., Kongsamut *et al.* (2001) consider non-unitary income elasticity of demand across sectors. Since income elasticity of agricultural goods is below one, the fraction of consumption expenditure declines as income expands. In a closed economy, where sectoral output and consumption are equalized in every period, this is followed by a decline in employment demand in agriculture. In this setting, structural change is driven by demand factors.

Alternatively, Ngai and Pissarides (2007) and Acemoglu and Guerrieri (2008) consider supply-side factors. The former view relies on differences in productivity growth rates across sectors, while the later in capital deepening and different capital intensities. If productivity grows faster in agriculture or

[1] Gollin *et al.* (2004) and Herrendorf *et al.* (2014), among others, summarize the evidence on this fact.

if the capital intensity is higher in this sector, the relative price of agricultural goods with respect to manufactures declines. If goods are complementary, a lower relative agricultural price implies lower demand in this sector. In a closed economy, this results in a decline in employment demand.

In an open economy, however, consumption and output can differ. A decline in domestic consumption in one sector can be compensated by higher foreign demand. In fact, as argued in Matsuyama (2009), the simultaneous rise in manufacturing productivity and employment in this sector, observed in East Asian economies, is at odds with a closed economy assumption. Using a theoretical model, he shows that a small open-economy, with growing manufacturing productivity, does not have to experience declining employment in this sector.

In a related paper, Uy *et al.* (2013) investigate the effect of international trade on structural change in South Korea. This country experienced a sharp decline in agricultural employment and an increase in employment in manufacturing and services, during the period 1971-2005. They find that a combination of non-homothetic preferences and trade can account for most of the structural change pattern observed in this country. Without trade, their model is unable to explain the sharp decline in agricultural employment observed in the data. Other models of structural change, using South Korea as a study case, are considered by Betts *et al.* (2013), Teignier (2014) and Sposi (2015). They all conclude that trade is important to explain structural change in South Korea.

The attention of the literature studying structural change in an open economy has been mostly focused on economies with comparative advantage in the manufacturing sector, such as South Korea. In this chapter, however, we study the case of net agricultural exporting countries. To quantify the role of agricultural trade in explaining the path of structural change, we consider a three-sector growth model and calibrate it to match patterns observed in Paraguay. This country experienced a significant rise in net agricultural exports as a percentage of aggregate output, during the period 1962-2012. The model includes non-homothetic preferences as in Kongsamut *et al.* (2001). According to Swiecki (2013), these preferences are key to account for structural change at an early stage of development. On the technology side, we consider differences in productivity grow rates and in capital intensities across sectors, as in Ngai and Pissarides (2007) and Acemoglu and Guerrieri

(2008). We enhance the model by including international trade in agricultural goods and manufacturing. The model is calibrated to match initial values in the data and is used to simulate the time path of endogenous variables.

We find that international trade is crucial to account for patterns of structural change observed in Paraguay. In fact, the simulation of the model indicates that increasing net agricultural exports affect employment composition in three ways. First, structural change out of agriculture is effectively slowed down, as employment demand remains large to satisfy a growing foreign demand. Second, it prevents a shift of employment from agriculture into manufacturing, as the growing consumption of manufacturing goods is satisfied by imports. Third, in the long-run employment shifts directly from agriculture into services, bypassing manufacturing.

Several papers studied the effect of international trade on structural change. Echevarria (1995) relates trade to the composition of output and economic growth. She calibrates a three-sector model and shows that, if a country specializes in agriculture, international trade increases growth at low levels of income but slows it down at higher levels. Stokey (2001), develops a multi-sector model and shows that trade, among other factors, had an impact on the rising share of manufacturing goods in aggregate output during the British industrial revolution. More recently, Swiecki (2013) studies the determinants of structural change in a panel of 45 countries. He finds that international trade is important to explain structural change in individual countries. None of these papers, however, has an explicit focus on structural change patterns of agricultural exporting countries.

An exception is Matsuyama (1992), who has already argued that the link between agricultural productivity and employment in agriculture can be positive in an open-economy, given comparative advantage in this sector. His approach, however, is purely theoretical, as opposed to this chapter where we provide an empirical quantification on the role of agricultural trade on structural change.

The rest of the chapter is organized as follows. We briefly describe the economy of Paraguay in the next section. Section 1.3 introduces the model. Section 1.4 shows the quantitative analysis, including the calibration and the simulation. Finally, Section 1.5 concludes.

1.2 Data description

Using data from the United Nations Food and Agricultural Organization (FAO), we compute net agricultural exports as percentage of gross domestic product (GDP) for all countries available in the database. We find 12 countries with net agricultural exports larger than 5% of GDP in 2012. These countries are listed in Table 1.1. Moreover, there are five countries with increasing net agricultural exports since 1970. We take Paraguay as a representative country of this group.

Figure 1.1 shows the evolution of GDP per capita in Paraguay (at constant national prices) taken from the Penn World Tables 8.1 during the period 1962-2011. We can observe a period of rapid growth between 1962 and 1981, stagnation until 2002, and moderate growth after 2003. On average, GDP per capita grew at a rate of 1.8% per year.

In this chapter, we consider the shift of employment across sectors as the measure of structural change. Figure 1.2 shows the composition of employment by sector in Paraguay. Employment in agriculture steadily declined from 55.1% in 1962 to 27.5% in 2002, and remained around that point until 2012. Employment in services rose from 25.6% in 1962 to 56.7% in 2012. Meanwhile, employment in manufacturing remained almost flat at 20% until the early 1990s and declined to 16% in 2012. There are two distinctive characteristics in this pattern. First, most of the labor in agriculture shifted directly into services, bypassing manufacturing. Second, despite a significant decline in agricultural employment, it remains large when compared to advanced economies where it has declined to less than one-digit levels. We argue that this pattern is, in part, related to the rise of net agricultural exports.

We construct a time series for net agricultural exports and net manufacturing imports in relation to aggregate output. We use data from United Nations Comtrade Database and the Central Bank of Paraguay (CBP). Figure 1.3 shows that until mid 1980s net agricultural exports averaged 6.1% of output while net manufacturing imports were slightly higher. From that point, there is an increasing trend in net agricultural exports followed by an increase in net manufacturing imports. By 2012, net agricultural exports accounted for 18.2% of aggregate output. This is a three-fold increase with respect to 1962. In the same figure, we can observe that international trade is near balanced from the second half of 1980s until 2012. Later in this chapter, we assume balanced trade based on this observation.

The rise in net agricultural exports observed in Figure 1.3 is attributed to an increase in exports of oilseeds, meats, and cereals. The combined net exports of these products increased from 0.7% of aggregate output in 1962 to 13.4% in 2012. In addition, we consider electricity exports as part of net agricultural exports, which increased from 0% of GDP in 1962 to 4.5% of GDP in 2012.[2] If not included, we would observe a widening difference between net agricultural exports and net manufacturing imports. Figure 1.4 breaks down the composition of net agricultural exports into the agricultural component and the electricity component. The increase in net agricultural exports, excluding electricity, is still sizable. It increases from 6.2% of aggregate output in 1962 to 13.7% in 2012, a more than two-fold increase. As in McMillan and Rodrik (2011), we take the large share of exports that is accounted for by agricultural goods in Paraguay as evidence of revealed comparative advantage in this sector.

We compute relative prices using sectoral value added in current and constant prices, taken from the CBP. Relative prices are given by $p_i = (V_i^n/V_i^c)/(V_m^n/V_m^c)$, where p_i is the price in units of manufacturing goods in sector $i = \{a, s\}$, agriculture and services, respectively. V^n is value added in current prices, while V^c is value added in constant prices. Figure 1.5 shows the evolution of relative prices. Both prices decline during the period and the decline is more pronounced for agricultural products. This implies that labor productivity is growing faster in both agriculture and services than in manufacturing.[3]

Finally, Figure 1.6 describes the evolution of the capital-output ratio (K/Y) in Paraguay. The data is taken from Pen World Tables 8.1. As the figure indicates, the ratio increases. Therefore, the role of capital accumulation cannot be disregarded when explaining patterns of structural change observed in this country.

In the next section, we introduce a model to explain the employment composition in Paraguay. To quantify the role of each driver of structural change, we calibrate the model using data on GDP per capita, relative prices, capital per capita and international trade.

[2]According to the Standard International Trade Classification (SITC), electricity is considered a primary product.

[3]This pattern is different from the one observed in the U.S., where the relative price of services increases, as described by Herrendorf *et al.* (2013).

1.3 The model

We consider a three-sector exogenous growth model. The representative household has non-homothetic preferences over the commodity set $i = \{a, m, s\}$, where a, m, and s stand for agricultural goods, manufactures, and services, respectively. Households supply labor inelastically to firms. The production functions are Cobb-Douglas. We introduce the three main drivers of structural change in the literature: non-unitary income elasticities, different productivity growth rates and different capital intensities. We introduce trade in agricultural and manufacturing goods. There are no labor or capital mobility frictions across sectors within countries, but they are immobile across countries. Moreover, there is no population growth and no transportation costs.

1.3.1 Preferences

The infinitely-lived representative household maximizes life-time utility given by[4]

$$U = \int_{t=0}^{\infty} e^{-\rho t} \ln[(c_a - \tilde{c}_a)^{\theta_a}(c_m)^{\theta_m}(c_s + \tilde{c}_s)^{\theta_s}]dt,$$

subject to the flow budget constraint

$$w + rK = p_a c_a + c_m + p_s c_s + \dot{K},$$

where c_a, c_m, and c_s denote consumption of agricultural and manufacturing goods and services. The subjective discount factor is given by ρ. The positive weights assigned to each item in the utility function are given by θ_a, θ_m, and θ_s and satisfy $\theta_a + \theta_m + \theta_s = 1$. The preference parameters $\tilde{c}_a$ and $\tilde{c}_s$ can be interpreted as minimum consumption requirements in agriculture and services, respectively. If either $\tilde{c}_a \neq 0$ or $\tilde{c}_s \neq 0$ then preferences are non-homothetic. The rental prices of labor and capital are denoted by w and r, while $\dot{K}$ stands for change in the stock of capital. Finally, p_a and p_s are the relative prices of agricultural goods and services in terms of manufactures.

The solution to the household's problem is characterized by the following equations

$$p_a c_a = \frac{\theta_a}{\theta_m} c_m + p_a \tilde{c}_a, \tag{1.1}$$

[4]We drop time sub-indexes for notational simplicity.

$$p_s c_s = \frac{\theta_s}{\theta_m} c_m - p_s \tilde{c}_s \tag{1.2}$$

and

$$\frac{\dot{c}_m}{c_m} = r - \rho. \tag{1.3}$$

Equations (1.1) and (1.2), respectively, define the demand of agricultural goods and services as a function of the consumption of manufacturing goods. Equation (1.3), the *Euler* equation, determines the time-path of consumption of manufacturing goods.

In addition, we define total expenditure as $E \equiv p_a c_a + c_m + p_s c_s$. Using (1.1) and (1.2) we can determine manufacturing consumption as a function of total expenditure as

$$c_m = \theta_m [E - (p_a \tilde{c}_a - p_s \tilde{c}_s)]. \tag{1.4}$$

1.3.2 Technology

There are three sectors in this economy. In each sector, a representative firm uses labor and capital to produce a homogeneous good. Technologies are given by

$$y_i = K_i^{\alpha_i} (A_i l_i)^{1-\alpha_i}, \tag{1.5}$$

where y_i denotes output in each sector. Capital K_i and labor l_i are the two inputs used for production. The labor-augmenting productivity A_i grows exogenously at a constant rate $\gamma_i > 0$. Productivity growth γ_i and capital intensity $\alpha_i \in (0,1)$ are sector specific.

Firms solve the following maximization problem

$$\max_{K_i, l_i} p_i y_i - w l_i - R K_i,$$

subject to (1.5). The cost that firms pay for renting capital is given by $R = r + \delta$, where δ stands for the depreciation rate of capital. The solution to this problem implies that

$$w = (1-\alpha_i) p_i A_i^{1-\alpha_i} k_i^{\alpha_i} \tag{1.6}$$

and

$$R = \alpha_i p_i A_i^{1-\alpha_i} k_i^{\alpha_i - 1}, \tag{1.7}$$

where $k_i = K_i / l_i$ is capital per worker in each sector. Equal wages and rental rates across sectors is an implication of free mobility of labor and capital across sectors within the country.

Using equations (1.6) and (1.7), we can relate capital per worker in agriculture and services to that of manufactures as

$$k_a = \Omega_1 k_m, \tag{1.8}$$

$$k_s = \Omega_2 k_m, \tag{1.9}$$

where $\Omega_1 = \alpha_a(1-\alpha_m)/\alpha_m(1-\alpha_a)$ and $\Omega_2 = \alpha_s(1-\alpha_m)/\alpha_m(1-\alpha_s)$. Therefore, capital per worker is larger in more capital-intensive sectors.

Finally, from equations (1.6), (1.8) and (1.9) we can obtain the following expressions for relative prices

$$p_a = \Omega_3 \frac{A_m^{1-\alpha_m}}{A_a^{1-\alpha_a}} k_m^{\alpha_m-\alpha_a} \tag{1.10}$$

and

$$p_s = \Omega_4 \frac{A_m^{1-\alpha_m}}{A_s^{1-\alpha_s}} k_m^{\alpha_m-\alpha_s}, \tag{1.11}$$

where $\Omega_3 = (\alpha_m/\alpha_a)^{\alpha_a}(1-\alpha_m/1-\alpha_a)^{1-\alpha_a}$ and $\Omega_4 = (\alpha_m/\alpha_s)^{\alpha_s}(1-\alpha_m/1-\alpha_s)^{1-\alpha_s}$. As equations (1.10) and (1.11) show, the growth of relative prices is determined by differences in productivity growth rates and by capital deepening when there are differences in capital intensities.

1.3.3 Market clearing and international trade

Full utilization of resources and no population growth implies

$$l_a + l_m + l_s = 1 \tag{1.12}$$

and

$$K_a + K_m + K_s = K,$$

that is, labor and capital demand in each sector equals total supply, where total labor supply is normalized to 1. Combining the previous two equations and (1.8) we obtain the inputs market-clearing condition

$$k_m = k/(\Omega_5 l_a + 1 + \Omega_6 l_s), \tag{1.13}$$

where k is the aggregate capital per worker, $\Omega_5 = (\Omega_1 - 1)$ and $\Omega_6 = (\Omega_2 - 1)$. From (1.8), (1.9) and (1.13) it follows that aggregate capital per worker and sectoral capital per worker are not equalized as long as capital intensities differ across sectors.

We introduce international trade in the following goods market clearing conditions

$$y_a = c_a + x_a, \tag{1.14}$$

$$y_m = c_m + \dot{k} + \delta k - x_m, \tag{1.15}$$

$$y_s = c_s, \tag{1.16}$$

where x_a stands for net agricultural exports and x_m for net manufacturing imports.[5] Therefore, production of agricultural goods can be used for either domestic consumption or exporting. Manufactures can be produced domestically or imported and they are used for domestic consumption, investing, and replacing depreciated capital. Services are non-tradeables.

As in Stokey (2001) and Yang and Zhu (2013), we assume that net agricultural exports are exogenously determined by foreign demand. In turn, net manufacturing imports adjust in every period to maintain balanced trade.[6] As shown in Section 1.2, balanced trade is a plausible assumption in Paraguay. We introduce the balance trade condition as

$$p_a x_a = x_m = x, \tag{1.17}$$

where x evolves exogenously. Condition (1.17) is consistent with the absence of capital mobility across countries, which implies that the interest rate R is determined endogenously in the model.

Finally, we can obtain an equation for aggregate output, $Y \equiv p_a y_a + y_m + p_s y_s$, using expressions (1.5) and (1.6) as

$$Y = (\Omega_7 l_a + 1 + \Omega_8 l_s) A_m^{1-\alpha_m} k_m^{\alpha_m}, \tag{1.18}$$

where $\Omega_7 = (1-\alpha_m)/(1-\alpha_a) - 1$ and $\Omega_8 = (1-\alpha_m)/(1-\alpha_s) - 1$.

[5] The variables x_a and x_m can adopt negative values, however in the parameterization of the model they adopt positive values to signify agricultural exports and manufacturing imports, respectively.

[6] Stokey (2001) and Yang (2013) take food imports as exogenous and assume balanced trade during the British industrial revolution.

1.3.4 Competitive equilibrium

We consider the de-trended variables $c = c_m/A_m$, $z = k/A_m$ and $z_m = k_m/A_m$. Using equations (1.3) and (1.7) we obtain

$$\frac{\dot{c}}{c} = \alpha_m z_m^{\alpha_m - 1} - \delta - \rho - \gamma_m, \tag{1.19}$$

where z_m is given by equation (1.13) as

$$z_m = z/(\Omega_5 l_a + 1 + \Omega_6 l_s). \tag{1.20}$$

Using equations (1.5), (1.12), (1.15), (1.17), and (1.18) we obtain the capital accumulation equation

$$\frac{\dot{z}}{z} = \frac{z_m^{\alpha_m}}{z}\Big(1 - l_a - l_s + (x/Y)(\Omega_7 l_a + 1 + \Omega_8 l_s)\Big) - \frac{c}{z} - \delta - \gamma_m, \tag{1.21}$$

where x/Y is the net agricultural exports to output ratio. Combining expressions (1.2), (1.5), (1.6), (1.11), and (1.16), we obtain an equation describing the employment share in services

$$l_s = \frac{1}{\Omega_9}\left(\frac{\theta_s}{\theta_m}\frac{c}{z_m^{\alpha_m}} - \frac{\Omega_4 \tilde{c}_s}{A_m^{\alpha_s} A_s^{1-\alpha_s} z_m^{\alpha_s}}\right), \tag{1.22}$$

where $\Omega_9 = (1-\alpha_m)/(1-\alpha_s)$. Finally, combining expressions (1.1), (1.5), (1.6), (1.10), (1.14), (1.17), and (1.18), we obtain an equation for the employment share in agriculture

$$l_a = \frac{1}{\Omega_{10}}\left(\frac{\theta_a}{\theta_m}\frac{c}{z_m^{\alpha_m}} + \frac{\Omega_3 \tilde{c}_a}{A_m^{\alpha_a} A_a^{1-\alpha_a} z_m^{\alpha_a}} + (x/Y)(\Omega_7 l_a + 1 + \Omega_8 l_s)\right), \tag{1.23}$$

where $\Omega_{10} = (1-\alpha_m)/(1-\alpha_a)$.

Given an initial condition for z and the exogenous processes A_a, A_m, A_s and x/Y, the dynamic equilibrium is defined as the sequence $\{c, z, z_m, l_a, l_m\}_{t=0}^{\infty}$ that solves the system of differential equations (1.19) and (1.21), and the static equations (1.20), (1.22) and (1.23).

1.3.5 Discussion

Equations (1.22) and (1.23) describe the evolution of employment in agriculture and services. To clarify the role of each driver of structural change, we redefine these equations in terms of aggregate output, Y, and total expenditure, E. Using (1.1), (1.2), (1.4), (1.5), (1.6), (1.14), (1.16), (1.17) and (1.18), we can restate employment shares as

$$\frac{\Omega_9 l_s}{\Omega_7 l_a + 1 + \Omega_8 l_s} = \theta_s \frac{E}{Y} - \frac{\theta_s p_a \tilde{c}_a + (1-\theta_s) p_s \tilde{c}_s}{Y},$$

and

$$\frac{\Omega_{10} l_a}{\Omega_7 l_a + 1 + \Omega_8 l_s} = \theta_a \frac{E}{Y} + \frac{(1-\theta_a) p_a \tilde{c}_a + \theta_a p_s \tilde{c}_s}{Y} + \frac{x}{Y},$$

where relative prices are defined in (1.10) and (1.11).

In these equations, employment shares are determined by the size of the value of minimum consumption requirements, $p_a \tilde{c}_a$ and $p_s \tilde{c}_s$, and the net agricultural exports to output ratio, x/Y. If we assume no trade ($x = 0$), equal productivity growth rates across sectors ($\gamma_a = \gamma_m = \gamma_s$) and equal capital intensities across sectors ($\alpha_a = \alpha_m = \alpha_s$), then relative prices, $\bar{p}_a$ and $\bar{p}_s$, are constant and employment shares are simplified to

$$l_s = \theta_s \frac{E}{Y} - \frac{\theta_s \bar{p}_a \tilde{c}_a + (1-\theta_s) \bar{p}_s \tilde{c}_s}{Y},$$

and

$$l_a = \theta_a \frac{E}{Y} + \frac{(1-\theta_a) \bar{p}_a \tilde{c}_a + \theta_a \bar{p}_s \tilde{c}_s}{Y}.$$

Clearly, as output Y grows, the minimum requirements vanish. Given that $\theta_s \bar{p}_a \tilde{c}_a + (1-\theta_s) \bar{p}_s \tilde{c}_s > 0$ and $(1-\theta_a) \bar{p}_a \tilde{c}_a + \theta_a \bar{p}_s \tilde{c}_s > 0$, employment in agriculture decreases while employment in services increases, as output grows. In the limit, when minimum consumption requirements disappear, employment shares are determined by the weights of agricultural goods and services in preferences, θ_a and θ_s, respectively. This is the mechanism described in Kongsamut *et al.* (2001) as the demand-side approach to structural change.

When productivity growth rates and capital intensities are different across sectors, supply-side mechanisms are active and operate through changing relative prices. Changes in relative productivities (A_m/A_i) and capital deepening when capital intensities are not equal ($\alpha_m \neq \alpha_i$) alter the path of relative prices (see equations (1.10) and (1.11)). This, in turn, affects the value of minimum consumption requirements and, therefore, the allocation of labor.

Finally, when the country is a net agricultural exporter, $x > 0$, minimum consumption requirements still vanish as income grows and/or relative prices decline. However, employment in the agricultural sector remains large in order to satisfy foreign demand. Clearly, this is the case as long as x/Y remains positive in the long run.

1.4 Quantitative analysis

1.4.1 Parameter values

We take the values $\delta = 0.05$ and $\rho = 0.02$ from Barro and Sala-i-Martin (2003). For capital intensity parameters, we use values estimated by Valentinyi and Herrendorf (2008) for the U.S. These values are $\alpha_a = 0.54$, $\alpha_m = 0.33$ and $\alpha_s = 0.34$. By doing so, we follow Restuccia *et al.* (2008) and calibrate the technology parameters to an economy with less frictions.

We set the utility weights θ_a, θ_m, and θ_s to match long run expenditure shares of developed countries.[7] We set these parameters to match expenditure shares in the U.S. ($\theta_i = p_i c_i / E$) as reported in Herrendorf *et al.* (2013) for value added consumption shares. The values are $\theta_a = 0.02$, $\theta_m = 0.13$ and $\theta_s = 0.85$. The preference parameters $\tilde{c}_a$ and $\tilde{c}_s$ are set to match employment shares in Paraguay in 1962. The calibrated values for $\tilde{c}_a$ and $\tilde{c}_s$ imply an income-elasticity for agricultural goods lower than for services, which in turn has an income-elasticity lower than for manufacturing goods.

We normalize the initial value of productivity in the manufacturing sector, $A_{m,0} = 1$, and set $A_{a,0}$ and $A_{s,0}$ to match relative prices p_a and p_s in 1962. The productivity growth rates, γ_a and γ_s, are in turn set to match the evolution of relative prices p_a and p_s, as described in Figure 1.5. Note that, to replicate the decline in both p_a and p_s, we need productivity growth rates and/or capital intensities in agriculture and services larger than in manufacturing. The productivity in manufactures, γ_m, is calibrated to match the long-run average annual growth rate of Paraguay during 1962-2011 of 1.8%.

[7] According to Gollin and Rogerson (2014), expenditure shares of rich countries provide information about preference parameters, since higher income implies non-homothetic terms close to zero.

As Figure 1.6 indicates, the capital-output ratio experienced a considerable increase since 1962 in Paraguay. Therefore, we set the initial value of the state variable z to 50% of its steady state value, to match the low capital-output ratio observed in 1962 in this country.

For the exogenous process x/Y we consider the formulation

$$\Phi_t = \Phi_{2012} - \frac{\Phi_{1962}}{e^{\mu_1 t}},$$

where $\Phi_t \equiv x_t/Y_t$, and Φ_{1962} and Φ_{2012} are parameters set to match a value of net agricultural exports of 6.1% of aggregate output in 1962 and a 18.2% in 2012. The parameter μ_1 controls the time it takes Φ_t to reach its final value. We set it to match as closely as possible the data in Figure 1.3. Table 1.2 summarizes the parameter targets and values.

1.4.2 Results

The benchmark model explains the employment trend in all sectors.[8] That is, a decline of employment share in agriculture, a rise in services and an almost flat manufacturing employment share. The resulting simulation is shown in Figure 1.7. The model simulates faster transition out of agriculture and is unable to replicate the kink observed after 2002, as expected. Furthermore, the model slightly underpredicts the employment share in services and over-predicts it in manufacturing after the mid-1990s, when employment in this sector declines in the data. However, the overall fit of the model appears to be good. Figure 1.8 shows the simulated series for relative prices and the exogenous process assumed for net agricultural exports.[9]

We test the relevance of each mechanism of structural change by turning it off and leaving the rest active. To turn international trade off, we set $x_t = 0$ for every period and recalibrate the preference parameters $\tilde{c}_a$ and $\tilde{c}_s$ to match initial employment shares in agriculture and services. Figure 1.9 summarizes the results. The following considerations are in order. First, employment in agriculture declines much faster without trade. By 2012, only 10% of the

[8]We solve the transitional dynamics of the model numerically, using the algorithm described by Trimborn *et al.* (2008).

[9]As a robustness check, we simulate the model without considering electricity as part of agricultural exports. We find no significant differences with respect to the results in this section.

workforce remains in this sector, as opposed to 27.2% observed in the data and 23.7% in the benchmark model. Second, employment in manufacturing increases considerably in this setting. Employment in this sector rises to 36%, considerably above the maximum observed in the data during the 1990s of 20%. Not surprisingly, given our choice of parameters, this behavior resembles the structural change pattern in a closed economy such as the U.S. Without trade, the model predicts a shift of employment from agriculture to manufacturing. This, however, is not observed in the data for Paraguay, as already discussed in Section 1.2. Finally, the time path of employment in services is only slightly affected when the economy is closed.

1.4.3 Quantifying the role of agricultural trade

Using the benchmark and counter-factual simulations, we can quantify the importance of international trade in explaining the pattern of structural change in Paraguay. For this purpose, we introduce the Labor Relocation Index (LRI) which is defined by Swiecki (2013) as

$$LRI = 1 - \frac{|\Delta l_a^{simul} - \Delta l_a^{data}| + |\Delta l_m^{simul} - \Delta l_m^{data}| + |\Delta l_s^{simul} - \Delta l_s^{data}|}{|\Delta l_a^{data}| + |\Delta l_m^{data}| + |\Delta l_s^{data}|}$$

where Δl_i^{data} is the observed difference between employment in sector i between 2012 and 1962, and Δl_i^{simul} is the same difference for the simulated data. According to Swiecki (2013), the index can be interpreted as the fraction of observed changes in employment shares attributed to the model under consideration. When $LRI = 1$, the simulation perfectly captures the pattern of employment in all sectors. When $LRI = 0$, the model does not explain employment reallocation. Finally, if $LRI < 0$ the model predicts structural change in the wrong direction, or predicts much larger changes. In addition, we define the Labor Relation Index for each sector as

$$LRI_i = 1 - \frac{|\Delta l_i^{simul} - \Delta l_i^{data}|}{|\Delta l_i^{data}|}.$$

We compute the LRI to formally evaluate the contribution of trade in structural change. We complement this measure with the R-squared statistic. Table 1.3 summarizes the results. The benchmark model explains 84.7% of observed changes in all employment shares between 1962 and 2012. When international trade is not considered, only 36.1% of observed changes can be accounted for by the model. When the LRI_i is computed for each sector, the model including trade consistently over-performs the closed economy model across sectors. Evidence provided by the R-square statistic is less conclusive, but it seems to favor the open-economy model as well. In sum, we conclude from this exercise that international trade is crucial to accurately describe the pattern of structural change in this country.

Finally, we test the contribution of the remaining structural change drivers. If we set equal productivity growth rates ($\gamma_a = \gamma_m = \gamma_s$) and equal capital intensities ($\alpha_a = \alpha_m = \alpha_s$), the model can only account for 73.1% of changes in employment, which is 11.6% below the benchmark model. If we consider homothetic preferences, the model predicts structural change in the wrong direction ($LRI < 0$). Clearly, this result follows from the fact that changing relative prices cannot generate structural change when preferences are homothetic and the elasticity of substitution across goods is unitary.

1.4.4 Transition to the balanced growth path

We simulate the transition to the balanced growth path to determine employment composition in the long-run. Note that, the economy approaches the balance growth path as income, Y, approaches infinity. We assume that the net agricultural exports to output ratio remains constant at 0.182, after the year 2012. Results from the simulation indicate that employment in agriculture declines to 14.5%. From the comparison between this value and the one predicted by the model for the year 2012 (23.7%), we conclude that 9.2% of the employment share allocated to agriculture is still employed to satisfy subsistence requirements. In addition, the model implies that employment shifts directly into services, as employment in this sector increases by 8.4% as we approach the balanced growth path.

From this exercise, we conclude that patterns of structural change in an agricultural exporting country are not going to be exactly as the ones described by Kuznets (1973) for developed economies. However, at this point a word of caution is necessary, as the absence of industrialization depends on our assumption that net agricultural exports continue to account for 18.2% of total output as we approach the balanced growth path.

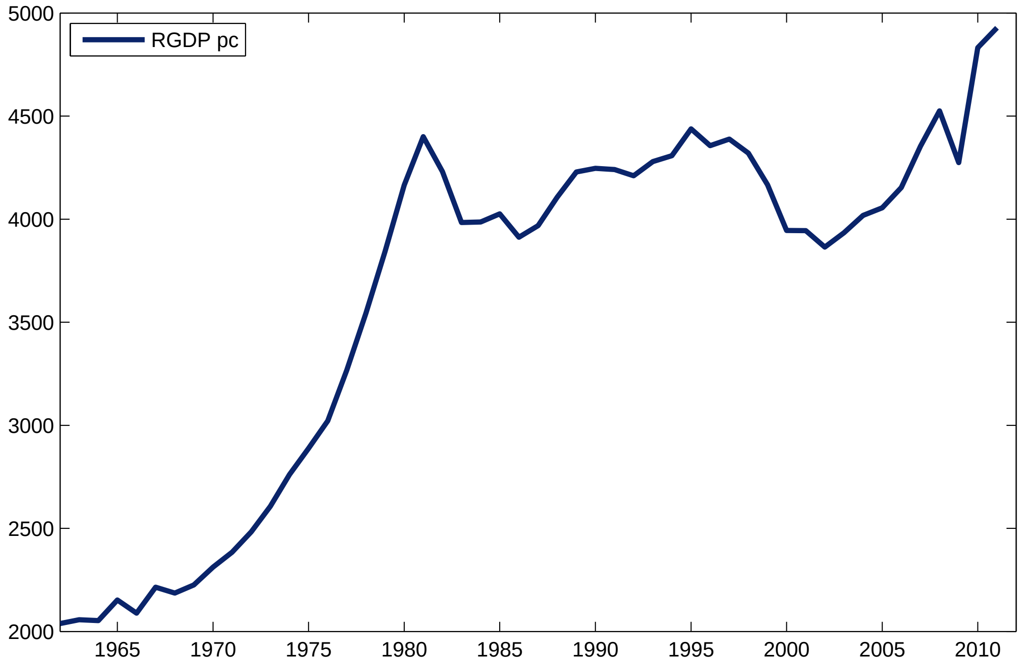
1.5 Concluding remarks

In this chapter, we study the effect of agricultural trade on structural change. For this purpose, we calibrate a three-sector model of exogenous growth to match structural change patterns observed in Paraguay. This country experienced a significant increase in net agricultural exports as a percentage of aggregate output during the period 1962-2012. The conclusions are threefold. First, international trade is crucial to account for structural change in this country. The model including trade explains 84.7% of changes in employment shares during this period, while the model without trade can only account for 36.1% of the changes. Second, whereas the expenditure share of consumption of agriculture declines, employment in this sector remains large in order to satisfy foreign demand. Third, in the long-run employment shifts directly from agriculture into services, bypassing manufacturing.

The main implication of this exercise is that patterns of structural change observed in currently advanced countries can differ from the ones in countries with sufficiently large agricultural exports. As discussed in Section 1.2, it is important to note that there are only a few countries with large net agricultural exports as a percentage of GDP. However, these results would apply to the case of countries that promote policies intended to increase comparative advantage in the production of agricultural goods and international trade. As we have shown in this chapter, such policies would result in a higher share of employment in agriculture at the expense of a lower employment share in manufacturing.

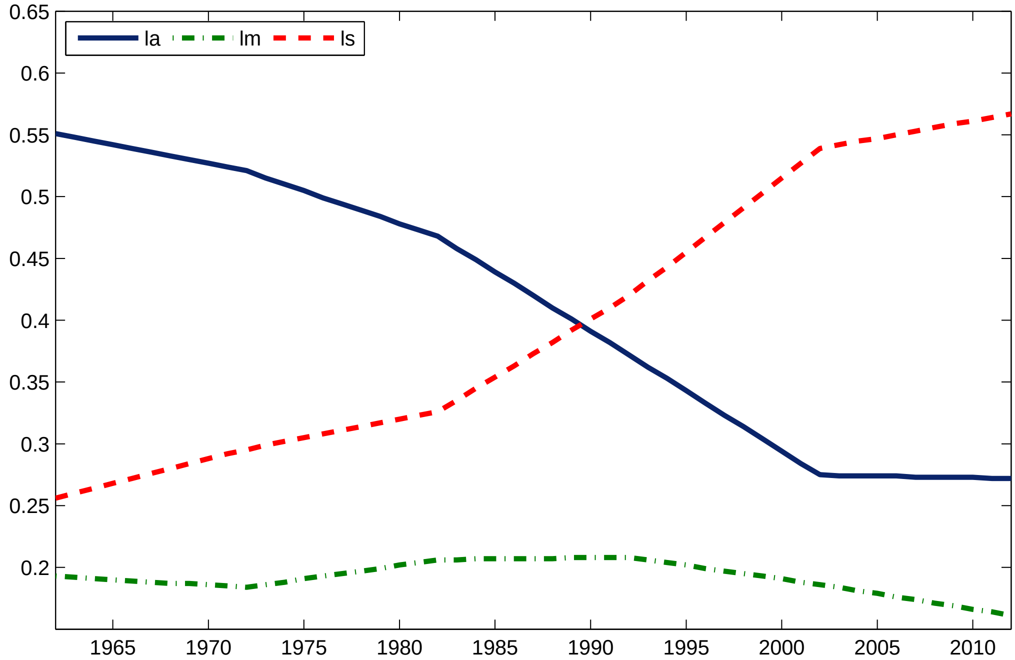
Appendix A. Figures and tables

Figure 1.1: Real GDP per capita



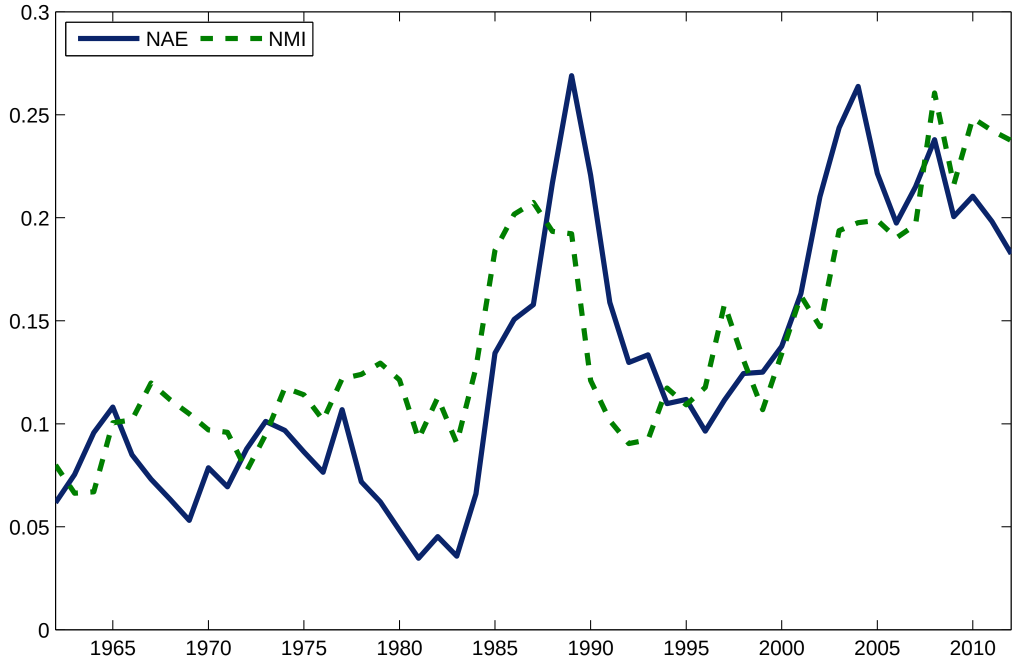
Source: Penn World Tables 8.1.
RGDP pc: Real GDP Per Capita at Constant 2005 National Prices (in 2005 US$).

Figure 1.2: Employment shares



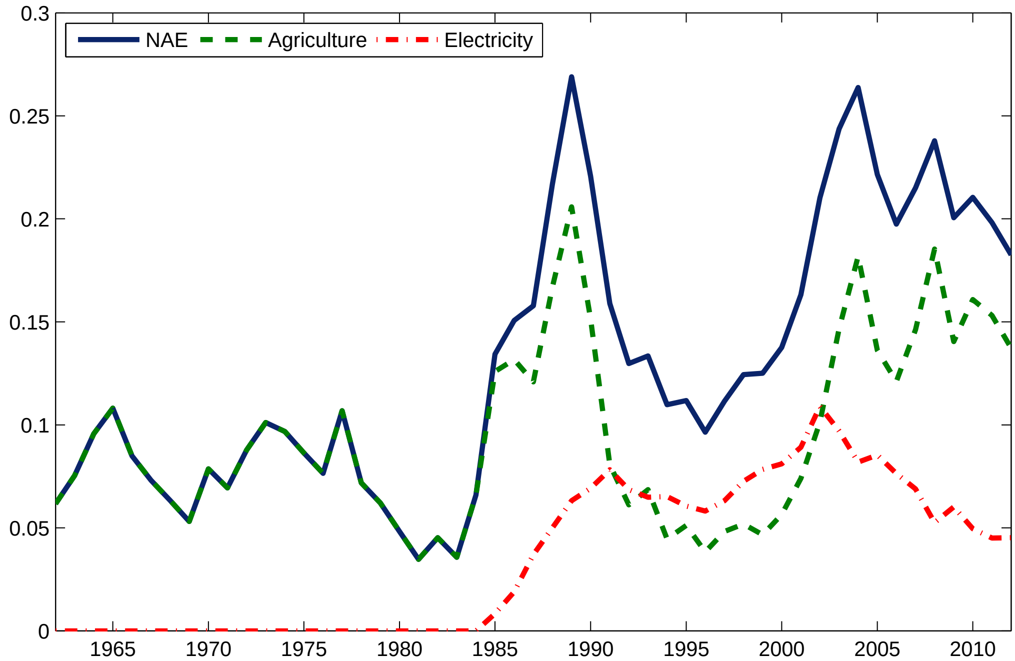
Source: National Statistical Agency of Paraguay (http://www.dgeec.gov.py/).
la: employment share in agriculture, lm: employment share in manufacturing, ls: employment share in services. Data for years 1962, 1972, 1982, 1992, 2002 taken from census data. Data for year 2012 taken from household surveys. We use a linear interpolation to fill the years in between.

Figure 1.3: Net agricultural exports and Net manufacturing imports



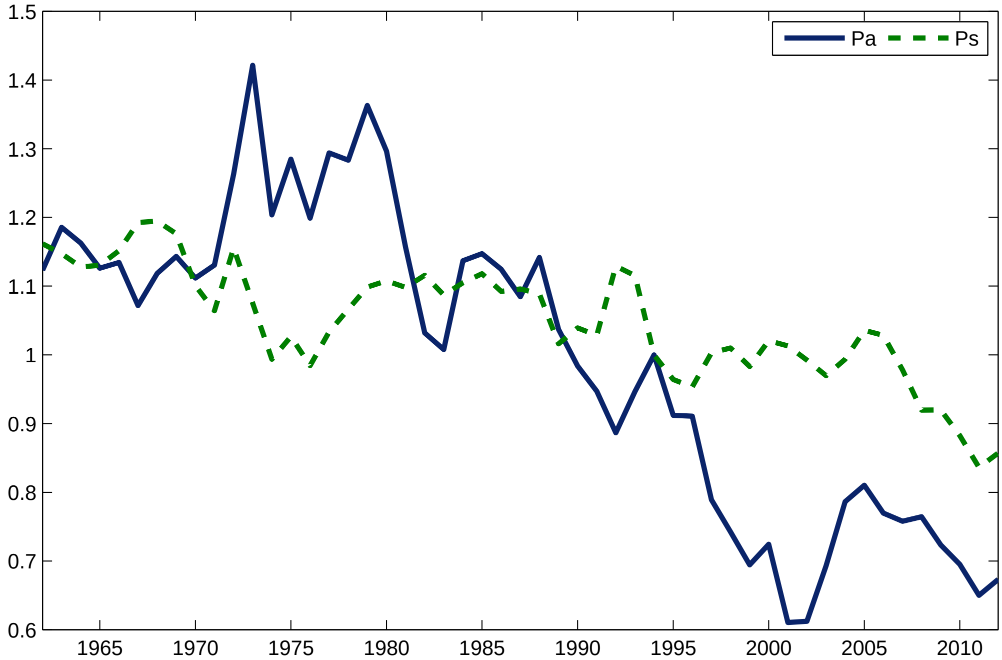
Source: UN Comtrade Database and Central Bank of Paraguay (CBP).
Net agricultural exports as % of GDP (NAE) includes exports minus imports of products in SITC rev. 1 sections 0, 1, 2, 4 minus division 27 and 28 from Comtrade. In addition, it includes net electricity exports (STIC rev. 1 division 35) and other exports taken from CBP to account for non-registered trade. We impute 50% of SITC division 35 as electricity exports, which we consider as the effective inflow of cash from electricity exports (the remaining 50% is destined to debt re-payment and other expenses).
Net manufacturing imports as % of GDP (NMI) includes imports minus exports of products in SITC rev. 1 sectios 3, 5, 6, 7, 8, divisions 27, 28 and 68 minus division 35. In addition, it includes other imports taken from the CBP to account for non-registered trade and we substract re-exports taken from the CBP from manufacturing imports.
Net agricultural exports for 2012 (18.2%) differs from the value reported in Table 1.1 (13.2%) due to electricity exports (4.5%) and differences in product classification (0.5%).

Figure 1.4: Net agricultural exports and Electricity



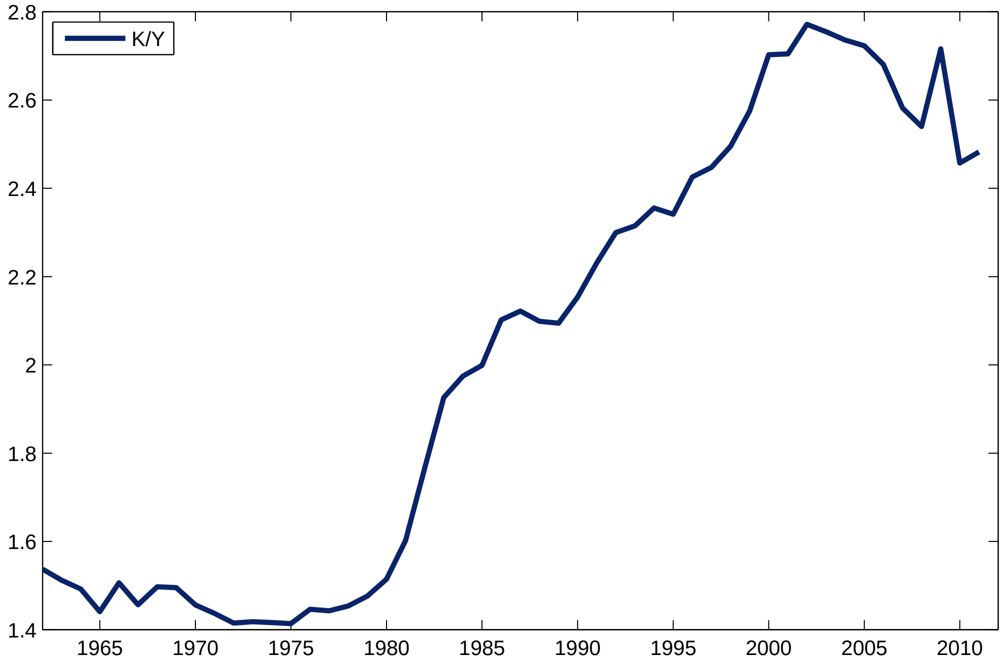
Source: UN Comtrade Database and Central Bank of Paraguay (CBP).
Net agricultural exports as % of GDP (NAE) includes exports minus imports of products in SITC rev. 1 sections 0, 1, 2, 4 minus division 27 and 28 from Comtrade. In addition, it includes net electricity exports (SITC rev. 1 division 35) and other exports taken from CBP to account for non-registered trade. We impute 50% of SITC division 35 as electricity exports, which we consider as the effective inflow of cash from electricity exports (the remaining 50% is destined for debt re-payment and other expenses).
Agriculture includes only net agricultural exports, that is NAE minus 50% of electricity (SITC rev. 1 division 35) exports.
Electricity includes 50% of electricity (SITC rev. 1 division 35) exports.

Figure 1.5: Relative prices



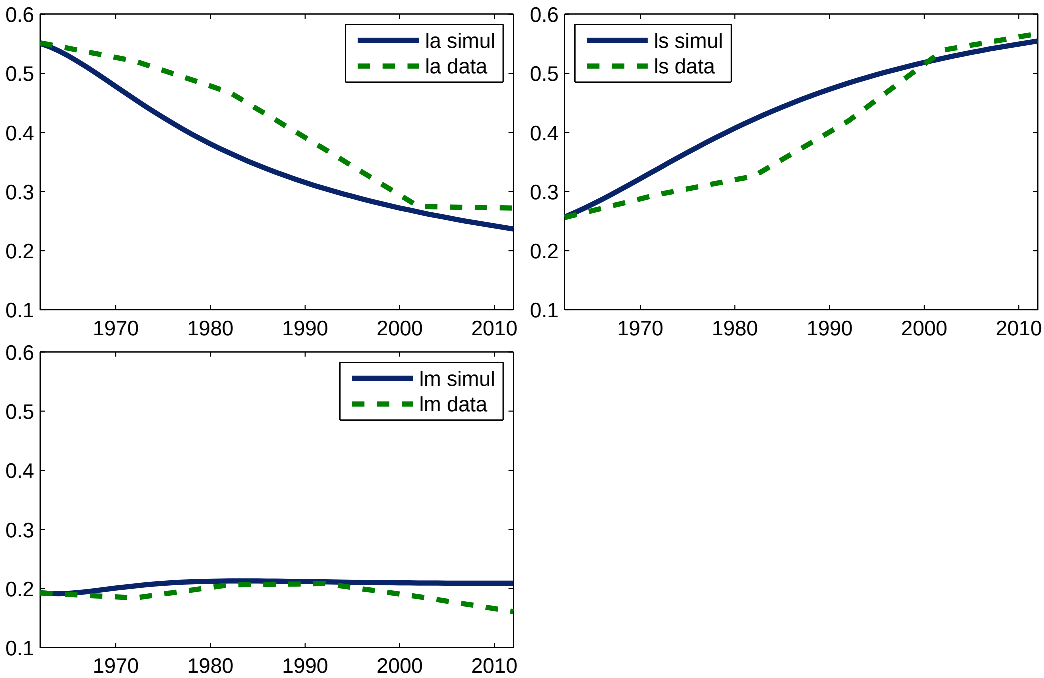
<u>Source</u>: Central Bank of Paraguay(CBP).
The relative price of agriculture (Pa) and services (Ps) in units of manufacturing goods are calculated as $p_a = (V_a^n/V_a^c)/(V_m^n/V_m^c)$ and $p_s = (V_s^n/V_s^c)/(V_m^n/V_m^c)$, where V_i^n indicates value added output in current prices and V_i^c value added output in constant prices, respectively, for sector $i = \{a, m, s\}$, that is agriculture, manufacturing and services, respectively.

Figure 1.6: Capital-Output ratio



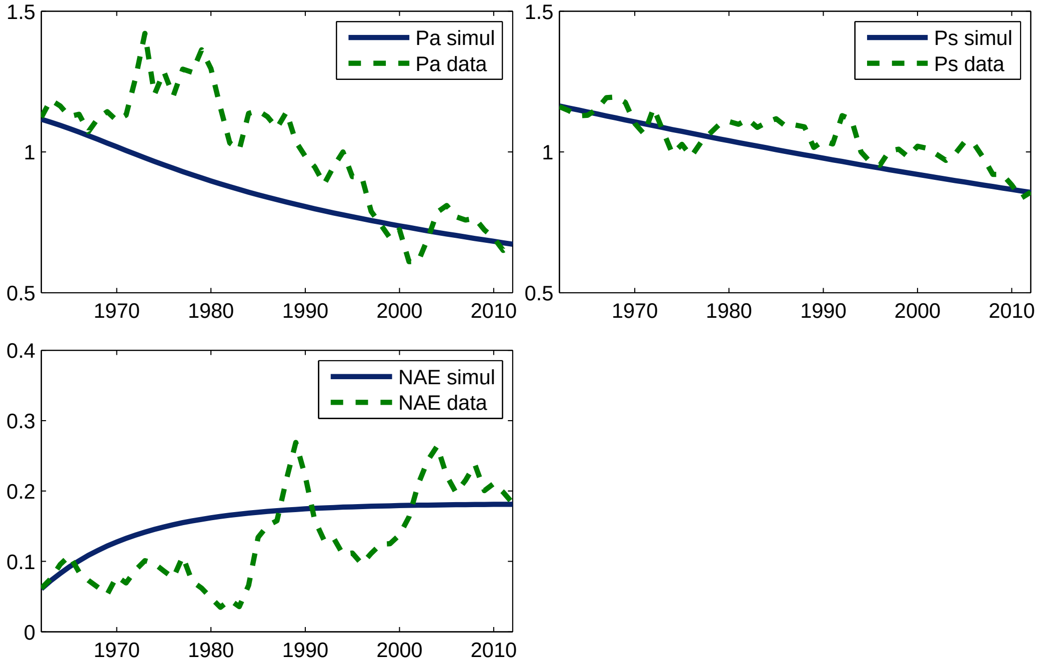
Source: Pen World Tables 8.1.
K indicates capital stock at constant 2005 national prices (in mil. 2005 US$) and Y indicates real GDP at constant 2005 national prices (in mil. 2005 US$).

Figure 1.7: Employment shares: benchmark model vs data



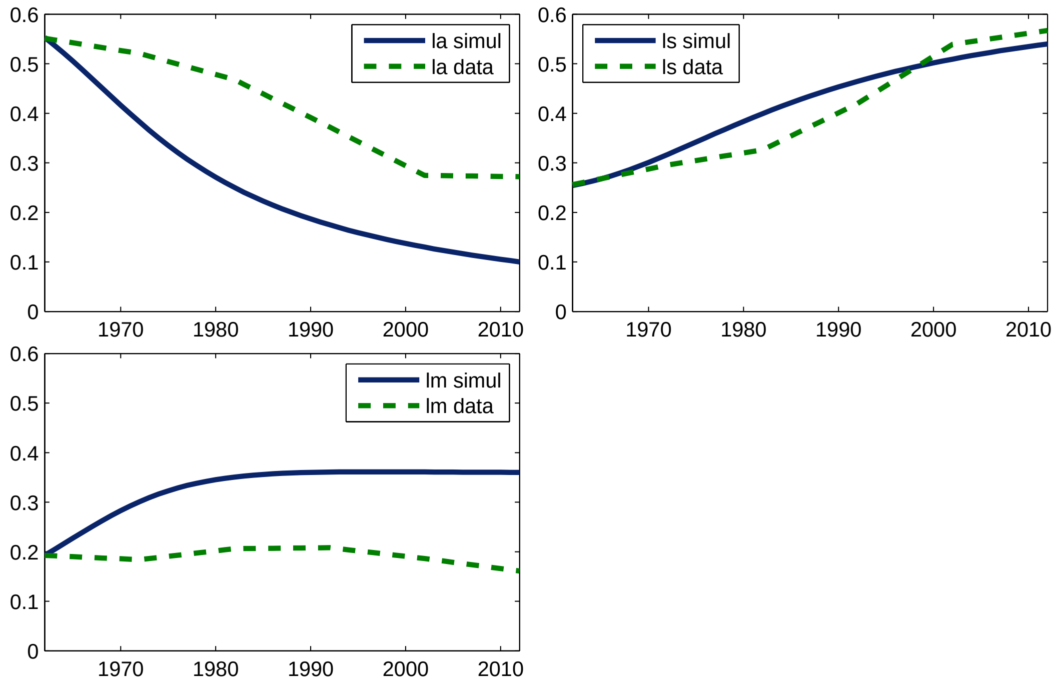
The variables la simul, lm simul and ls simul indicate employment share in agriculture, manufacturing and services, respectively, generated by the model. The variables la data, lm data and ls data indicate employment share in agriculture, manufacturing and services, respectively, observed in the data.

Figure 1.8: Relative prices and Net agricultural exports: model vs data



The variables Pa simul, Ps simul and NAE simul indicate relative price of agriculture, relative price of services and net agricultural exports, respectively, generated by the model. The variables Pa data, Ps data and NAE data indicate relative price of agriculture, relative price of services and net agricultural exports, respectively, observed in the data.

Figure 1.9: Employment shares: data vs model without trade



The variables la simul, lm simul and ls simul indicate employment share in agriculture, manufacturing and services, respectively, generated by the model. The variables la data, lm data and ls data indicate employment share in agriculture, manufacturing and services, respectively, observed in the data.

Table 1.1: Net agricultural exports by country

Country	NAE_{2012}	NAE_{2012}/NAE_{1970}
Argentina	6.4	1.740
Belize	5.2	0.709
Cote d'Ivoire	13.4	0.810
Guyana	5.5	0.766
Honduras	5.3	0.443
Malawi	10.0	1.726
New Zealand	9.2	0.674
Nicaragua	10.2	1.073
Paraguay	13.2	2.059
Thailand	5.2	0.934
Ukraine	6.1	-
Uruguay	9.2	1.729

Source: United Nations Food and Agricultural Organization (FAO).
Net agricultural exports as % of GDP (NAE) includes all crops and livestock products. NAE_{2012}/NAE_{1970} is the ratio of NAE_{2012} with respect to NAE_{1970}, a value larger than one indicates an increase of NAE.

Table 1.2: Calibration

Parameter	Target	Value
δ	Barro and Sala-i-Martin (2003)	0.05
ρ	Barro and Sala-i-Martin (2003)	0.02
α_a	Valentinyi and Herrendorf (2008)	0.54
α_m	Valentinyi and Herrendorf (2008)	0.33
α_s	Valentinyi and Herrendorf (2008)	0.34
γ_m	Long-run aggregate growth rate of 1.8%	0.0180
γ_a	Time-path of p_a	0.0315
γ_s	Time-path of p_s	0.0270
$A_{m,0}$	Normalization	1
$A_{a,0}$	Value of p_a in 1962	0.2
$A_{s,0}$	Value of p_s in 1962	0.761
z_0	Initial capital-output ratio	$0.5 * z_{ss}$
$\bar{x}_{ini}$	Agricultural exports in 1962 (% of GDP)	0.121
$\bar{x}_{fin}$	Agricultural exports in 2012 (% of GDP)	0.182
μ_1	Agricultural exports from 1962 to 2012 (% of GDP)	0.1
θ_a	Herrendorf *et al.* (2013)	0.02
θ_s	Herrendorf *et al.* (2013)	0.85
$\tilde{c}_a$	Agricultural labor shares in 1962	0.875
$\tilde{c}_s$	Services labor share in 1962	-0.160

Table 1.3: Model evaluation

Variable	Model	LRI	R-squared
l_a	Benchmark	0.8775	0.9046
l_m	Benchmark	-0.5093	0.0797
l_s	Benchmark	0.9570	0.8845
Total	Benchmark	0.8469	-
l_a	No trade	0.3784	0.8552
l_m	No trade	-5.3029	0.0088
l_s	No trade	0.9192	0.9079
Total	No trade	0.3607	-
l_a	Homothetic preferences	-0.3308	0.6487
l_m	Homothetic preferences	-4.4926	0.0000
l_s	Homothetic preferences	0.3613	0.6210
Total	Homothetic preferences	-0.1958	-
l_a	Equal α's and γ's	0.7001	0.9758
l_m	Equal α's and γ's	0.3074	0.0451
l_s	Equal α's and γ's	0.8008	0.8899
Total	Equal α's and γ's	0.7306	-

2 Monetary Policy and Sectoral Composition

2.1 Introduction[1]

One of the main objectives of monetary policy is stabilizing inflation. A key issue for central banks, seeking to meet this goal, is to define a measure of inflation to target. This measure should allow the monetary authority to minimize the welfare loss that arises due to nominal frictions present in the economy. In this chapter, we study what is the optimal measure of inflation that a central bank should target, given the sectoral composition of the economy in which it operates.

From the structural change literature, we know that sectoral composition changes as the economy grows.[2] Developing countries have a larger share of agricultural consumption compared to developed nations. Therefore, a direct implication for monetary policy purposes is that agricultural prices have a larger weight in the aggregate price index in these economies. If we define the measure of inflation as a weighted average of inflation rates across sectors, where the weights are determined by the central bank, then, is it optimal for a central bank in a developing country to assign a large weight to agricultural inflation?

To answer this question, we build a multi sector model that includes features from the structural change and new Keynesian literature. We consider an economy with two sectors: agriculture and non-agriculture. In the model, agricultural goods have lower-than-one income elasticity and price elasticity is non-unitary.[3] In a developing country, low aggregate productivity and

[1] This chapter was written in collaboration with Sebastian Diz.

[2] Herrendorf *et al.* (2014) provide a review of the structural change literature.

[3] Kongsamut *et al.* (2001) examine structural change when income elasticities are different across sectors. Ngai and Pissarides (2004) and Acemoglu and Guerrieri (2008) examine conditions for structural change when price elasticity is non-unitary.

low relative agricultural productivity imply low income level and high relative price of agricultural goods. Therefore, the shares of consumption and employment in agriculture are high. We refer to an economy with this feature as a country in an early stage of structural change. Clearly, as aggregate and relative agricultural productivity rise, sectoral composition shifts to non-agriculture.

Regarding the new Keynesian features of the model, we consider an economy with flexible prices in agriculture, sticky prices in non-agriculture and sticky wages in both sectors. We consider flexible prices in the agricultural sector, based on the findings of Bils and Klenow (2004) for the United States. These authors indicate that the frequency of price changes for unprocessed food is much higher than the average. We assume there are no labor mobility frictions across sectors, even at business cycle frequency. Wage stickiness is assumed to be equal across sectors based on evidence provided by Barattieri *et al.* (2004), who argued that there is little heterogeneity in the frequency of wage adjustment across industries and occupations in the United States. In the model, countries in an early stage of structural change will have a high concentration of flexible prices in the aggregate price index, as the agricultural consumption share is high.

We set the parameters of the model to match the structural change features of a developing country, that is, large employment and consumption in agriculture as percentage of total employment and expenditure, respectively. We evaluate welfare losses when the economy is hit by sector specific productivity shocks, using a Taylor rule with different weights assigned to agricultural and non-agricultural inflation. We compute the optimal measure of inflation, that is, the weight of agricultural inflation that allows the central bank to minimize welfare loss. We then compare the baseline results of a developing country to those of a rich economy.

Results show that optimal weights depend on the type of shock hitting the economy. Productivity shocks to the flexible agricultural sector imply a zero weight on agricultural inflation. On the other hand, productivity shocks to the sticky non-agricultural sector imply a full weight on agricultural inflation. In addition, we find that optimal weights are equal for countries with different sectoral composition. However, the sectoral composition of the economy affects the welfare gain that a central bank can attain by targeting the optimal measure of inflation.

To understand these results we examine the impulse responses generated by the model and derive a welfare loss function to analyze the sources of welfare loss. The impulse responses, after non-agricultural productivity shocks, show that there is a link between agricultural price inflation and wage inflation. The reason is that, with perfect mobility across sectors, wages are proportional to agricultural prices. Targeting agricultural inflation allows the central bank to reduce wage inflation and, indirectly, non-agricultural inflation, since wages are part of marginal costs in this sector. In fact, using the welfare loss function we find that wage inflation is the main source of welfare loss, followed by non-agricultural price inflation, given the choice of parameters. On the other hand, the impulse responses, after agricultural productivity shocks, show that targeting agricultural prices actually increases wage and price inflation. Therefore, the central bank minimizes welfare loss by targeting non-agricultural inflation.

The most closely related findings in the literature are those of Aoki (2001), Mankiw and Reis (2003), Anand *et al.* (2015) and Portillo *et al.* (2016). Aoki (2001) uses a new Keynesian model with a flexible price sector and a sticky price sector. He shows that stabilizing sticky price inflation is sufficient to stabilize inflation around its efficient level. This analysis was expanded in Mankiw and Reis (2003), who ask what is the measure of inflation that central banks should target in order to stabilize the economy. They show that central banks should weight a sector in the price index given its characteristics, which include price stickiness, size, cyclical sensitivity and magnitude of sectoral shocks.

More recently, Anand *et al.* (2015) consider segmented labor and incomplete credit markets. That is, workers cannot move across sectors in the economy, while households in the agricultural sector have no access to banking services. They find that, in these circumstances, it is optimal for the central bank to target headline inflation, defined as a broad measure including agricultural prices. The reason is that agricultural productivity shocks affect real wages of households in this sector, which in turn affect aggregate demand. To contain demand and price volatility, the central bank must include agricultural prices in the target. Portillo *et al.* (2016) consider a two sector model with subsistence consumption of food, and demand and agricultural productivity shocks. Their findings indicate that it is optimal for central banks to target only core inflation, a measure excluding volatile food prices, and losses from missing this target are larger for poorer countries.

In this chapter we find, as in Anand *et al.* (2015), that the central bank should target agricultural inflation to minimize welfare loss. As opposed to Anand *et al.* (2015), we do not need to consider financial frictions and immobile workers. We only have to consider sticky wages, a robust feature of the data. In addition, the model in this chapter can account for the results of Aoki (2001) and Portillo *et al.* (2016), when only agricultural productivity shocks hit the economy. In sum, the main contributions of this chapter are two-fold. First, we show how sticky wages affect the optimal measure of inflation that a central bank should target. Second, we show that welfare gains in economies with the sectoral composition of developed countries can be substantial, if central banks assign weight to agricultural inflation after shocks to non-agricultural productivity, and that this is equivalent to targeting wage inflation.

The rest of the chapter is organized as follows. The next section introduces the model. Section 2.3 describes the quantitative exercise, including parameter selection, results from the simulation and sensitivity analysis. Section 2.4 introduces the welfare loss function. Finally, Section 2.5 concludes.

2.2 Model

2.2.1 Firms

The economy consists of two sectors: agriculture and non-agriculture, denoted by $s \in \{a, n\}$. In each sector there is a continuum of firms, indexed by $i \in [0, 1]$, producing a single-differentiated good and with monopoly power to set prices. Production technologies are given by

$$Y_{s,t}(i) = A_{s,t} N_{s,t}(i)^{1-\alpha_s}, \tag{2.1}$$

where $Y_{s,t}(i)$ is output of firm i in sector s. Productivity levels, denoted by $A_{s,t}$, are common for all firms in the same sector. $N_{s,t}(i)$ is and index of labor inputs demanded by firm i in sector s, and is defined as

$$N_{s,t}(i) \equiv \left(\int_0^1 N_{s,t}(i,j)^{\frac{\varepsilon_w - 1}{\varepsilon_w}} dj \right)^{\frac{\varepsilon_w}{\varepsilon_w - 1}}, \tag{2.2}$$

where $N_{s,t}(i,j)$ denotes labor variety $j \in [0,1]$. The firm regards different labor varieties as imperfect substitutes of each other. The parameter $\varepsilon_w > 0$ is the elasticity of substitution across labor varieties and is common in both sectors.

Firm i takes the wage of labor variety j, $W_t(j)$, as given in each period. Labor demand of firm i in sector s of labor variety j is determined by solving the firm's cost minimization problem (derivations in the Appendix A.1). It is given by

$$N_{s,t}(i,j) = \left(\frac{W_t(j)}{W_t}\right)^{-\varepsilon_w} N_{s,t}(i), \tag{2.3}$$

where the wage index (W_t) is defined as

$$W_t \equiv \left(\int_0^1 W_t(j)^{1-\varepsilon_w} dj\right)^{\frac{1}{1-\varepsilon_w}}. \tag{2.4}$$

Optimal price setting

In every period, firms in sector s reset prices with probability $(1-\theta_s)$, as in Calvo (1983). The probability of resetting the price is sector specific. A firm in sector s that last reset prices in period t, chooses the price that maximizes the following sum of discounted profits

$$\max_{P^*_{s,t}} \sum\nolimits_{k=0}^{\infty} \theta_s^k \mathbb{E}_t \left\{ Q_{t,t+k} \left[P^*_{s,t} Y_{s,t+k|t} - TC_{t+k}(Y_{s,t+k|t}) \right] \right\}$$

subject to the demand constraint given by[4]

$$Y_{s,t+k|t} = \left(\frac{P^*_{s,t}}{P_{s,t+k}}\right)^{-\varepsilon_p} C_{s,t+k},$$

where $P^*_{s,t}$ is the optimal price of a firm that last reset its price at t, $Y_{s,t+k|t}$ is the output of that firm, $P_{s,t+k}$ is the price of good s available at time $t+k$ and $C_{s,t+k}$ indicates total demand of that good. $\varepsilon_p > 0$ is the elasticity of substitution across goods varieties. Firms discount profits by the state-contingent stochastic discount factor, $Q_{t,t+k}$, as defined in Erceg *et al.* (2000), and by the probability that the firm will not reset prices next period, θ_s. The total cost of producing $Y_{s,t+k|t}$ units of output is defined as $TC_{t+k}(Y_{s,t+k|t}) \equiv$

[4] We derive the demand constraint, in Appendix A.2.

$W_{t+k}N_{s,t+k|t}$.

Maximization implies

$$\sum_{k=0}^{\infty}(\theta_s)^k \mathbb{E}_t \left\{ Q_{t,t+k} Y_{s,t+k|t} \left[P^*_{s,t} - \mu_p MC^n_{s,t+k|t} \right] \right\} = 0, \qquad (2.5)$$

where $MC^n_s \equiv \partial TC(Y_s)/Y_s$ is the nominal marginal cost of producing one more unit of output in sector s, and $\mu_p \equiv \varepsilon_p/(\varepsilon_p - 1)$ is the desired markup, common to both sectors.

When prices are flexible ($\theta_s = 0$), prices are given by the desired mark-up over the nominal marginal cost as

$$P^*_{s,t} = P_{s,t} = \mu_p MC^n_{s,t}.$$

2.2.2 Households

There is a continuum of households indexed by $j \in [0,1]$ with life-time utility given by

$$\mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t(j)^{1-\sigma}}{1-\sigma} - \frac{N_t(j)^{1+\varphi}}{1+\varphi} \right) \right\},$$

where $C_t(j)$ is a consumption index and $N_t(j)$ is labor supply. Each household j supplies a different variety of labor and has monopoly power to set wages. The consumption index is an aggregate of agricultural and non-agricultural goods consumption. It is defined as

$$C_t(j) \equiv \left(\omega_a^{\frac{1}{\gamma}} (C_{a,t}(j) - \tilde{C}_a)^{\frac{\gamma-1}{\gamma}} + \omega_n^{\frac{1}{\gamma}} C_{n,t}(j)^{\frac{\gamma-1}{\gamma}} \right)^{\frac{\gamma}{\gamma-1}},$$

where $C_{a,t}(j)$ and $C_{n,t}(j)$ are in turn consumption indexes comprising the different varieties of goods available in each sector, and are defined as

$$C_{s,t}(j) \equiv \left(\int_0^1 C_{s,t}(i,j)^{\frac{\varepsilon_p - 1}{\varepsilon_p}} di \right)^{\frac{\varepsilon_p}{\varepsilon_p - 1}},$$

where $C_{s,t}(i,j)$ denotes household j's consumption of good variety i available in sector $s \in \{a,n\}$.

The parameter β indicates the discount factor, $1/\sigma$ is the intertemporal elasticity of substitution, $1/\varphi$ is the Frisch elasticity of labor supply. ω_a and ω_n are the utility weights of agriculture and non-agriculture and satisfy

$\omega_a + \omega_n = 1$, $\gamma \in (0,1)$ is the elasticity of substitution between agricultural and non-agricultural goods (when preferences are homothetic), $\tilde{C}_a$ is the agricultural minimum consumption requirement (when $\tilde{C}_a \neq 0$, preferences are non-homothetic), and $\varepsilon_p > 1$ is the elasticity of substitution across goods varieties, common in both sectors.

The budget constraint of household j is given by

$$\int_0^1 P_{a,t}(i)C_{a,t}(i,j)di + \int_0^1 P_{n,t}(i)C_{n,t}(i,j)di + Q_t B_t(j) = W_t(j)N_t(j) \\ +B_{t-1}(j) + \Pi_t(j).$$

Households receive labor income, $W_t(j)N_t(j)$, and profits, $\Pi_t(j)$, from equal ownership of firms. They spend income to consume and accumulate the state-contigent asset B_t, valued at price Q_t.

Intratemporal optimization

In each period, household j determines the optimal consumption allocation given total expenditure (derivations in the Appendix A.3) Optimization implies the following consumption demand function

$$C_{s,t}(i,j) = C_{s,t}(j)\left(\frac{P_{s,t}(i)}{P_{s,t}}\right)^{-\varepsilon_p}, \tag{2.6}$$

where $C_{s,t}(j)$ indicates total demand of good s, and the price index in sector s is defined as

$$P_{s,t} \equiv \left(\int_0^1 P_{s,t}(i)^{1-\varepsilon_p} di\right)^{\frac{1}{1-\varepsilon_p}}. \tag{2.7}$$

The optimal consumption allocation satisfies the following condition

$$\frac{C_{a,t}(j) - \tilde{C}_a)}{C_{n,t}(j)} = \frac{\omega_a}{\omega_n}\left(\frac{P_{a,t}}{P_{n,t}}\right)^{-\gamma}. \tag{2.8}$$

In turn, household j's total demand of good $s \in \{a,n\}$ is given by (derivations in the Appendix A.4)

$$C_{n,t}(j) = \omega_n \left(\frac{P_{n,t}}{P_t}\right)^{-\gamma} C_t(j) \tag{2.9}$$

and

$$C_{a,t}(j) = \tilde{C}_a + \omega_a \left(\frac{P_{a,t}}{P_t} \right)^{-\gamma} C_t(j), \tag{2.10}$$

where the aggregate price index is defined as

$$P_t \equiv \left(\omega_a P_{a,t}^{1-\gamma} + \omega_n P_{n,t}^{1-\gamma} \right)^{\frac{1}{1-\gamma}}. \tag{2.11}$$

Using equation (2.6) we can derive aggregate expenditure at sectoral level as $\int_0^1 P_{s,t}(i) C_{s,t}(i,j) di = P_{s,t} C_{s,t}(j)$. Using this expression and equations (2.9)-(2.11), we can express the budget constraint of household j as

$$P_t C_t(j) + Q_t B_t(j) = W_t(j) N_t(j) + B_{t-1}(j) + \Pi_t(j) - P_{a,t} \tilde{C}_a, \tag{2.12}$$

where $P_t C_t(j)$ is household j's total expenditure excluding the value of the minimum consumption requirement, $P_{a,t} \tilde{C}_a$.

Optimal wage setting

In every period, households reset wages with probability $(1 - \theta_w)$, as in Erceg *et al.* (2000). Households set their optimal wage, W_t^*, solving the following problem

$$\max_{W_t^*} \mathbb{E}_t \left\{ \sum_{k=0}^{\infty} (\theta_w \beta)^k \left(\frac{C_{t+k|t}^{1-\sigma}}{1-\sigma} - \frac{N_{t+k|t}^{1+\varphi}}{1+\varphi} \right) \right\}$$

subject to the labor demand given by[5]

$$N_{t+k|t} = \left(\frac{W_t^*}{W_{t+k}} \right)^{-\varepsilon_w} N_{t+k}$$

and the budget constraint (2.12). $C_{t+k|t}$ and $N_{t+k|t}$ indicate consumption and labor supply of a household that last re-optimized wage in period t.

Maximization implies

$$\sum_{k=0}^{\infty} (\theta_w \beta)^k \mathbb{E}_t \left\{ C_{t+k|t}^{-\sigma} N_{t+k|t} \left(\frac{W_t^*}{P_{t+k}} - \mu_w MRS_{t+k|t} \right) \right\} = 0, \tag{2.13}$$

where $\mu_w \equiv \varepsilon_w / (\varepsilon_w - 1)$ is the desired wage markup and

[5] We derive the labor demand constraint in Appendix A.2.

the marginal rate of substitution is defined as $MRS_{t+k|t} \equiv -U_n(C_{t+k|t}, N_{t+k|t})/U_c(C_{t+k|t}, N_{t+k|t}) = C^{\sigma}_{t+k|t} N^{\varphi}_{t+k|t}$.

When wages are flexible ($\theta_w = 0$), the real wage is given by the desired mark up over the marginal rate of substitution

$$\frac{W_t^*}{P_t} = \frac{W_t}{P_t} = \mu_w MRS_t = \mu_w C_t^{\sigma} N_t^{\varphi}.$$

Intertemporal problem

Intertemporal optimization implies the following *Euler* equation

$$Q_t = \beta \mathbb{E}_t \left\{ \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \right\}, \tag{2.14}$$

where Q_t is the stochastic discount factor. As in Erceg *et al.* (2000), we assume that households have access to complete assets markets for consumption, which implies identical consumption across households in very period ($C_t(j) = C_t$).

2.2.3 Price and wage dynamics

Since all firms and households that re-optimize choose the same price and wage, price dynamics in sector s is given by

$$P_{s,t}^{1-\varepsilon_p} = \theta_s P_{s,t-1}^{1-\varepsilon_p} + (1-\theta_s) P_{s,t}^{*1-\varepsilon_p}, \tag{2.15}$$

and wage dynamics by

$$W_t^{1-\varepsilon_w} = \theta_w W_{t-1}^{1-\varepsilon_w} + (1-\theta_w) W_t^{*1-\varepsilon_w}. \tag{2.16}$$

Price inflation in sector s is defined as $\Pi_{s,t} \equiv P_{s,t}/P_{s,t-1}$, while wage inflation is defined as $\Pi_{w,t} \equiv W_t/W_{t-1}$.

2.2.4 Market clearing and aggregation

Goods market clearing implies

$$Y_{s,t}(i) = \int_0^1 C_{s,t}(i,j) dj, \tag{2.17}$$

that is, output of firm i in sector s satisfies demand of all households for that product variety.

Aggregate output in sector s is defined as $Y_{s,t} \equiv (\int_0^1 Y_{s,t}(i)^{\frac{\varepsilon_p - 1}{\varepsilon_p}} di)^{\frac{\varepsilon_p}{\varepsilon_p - 1}}$, which can be interpreted as a final good producer in sector s using as inputs the output of intermediate firms in the same sector. Combining this definition with equations (2.6), (2.17) and the definition of sectoral prices, $P_{s,t}$, we obtain

$$Y_{s,t} = \int_0^1 C_{s,t}(j)dj = C_{s,t}, \tag{2.18}$$

where the last equality follows form the complete asset markets assumption.

Aggregate employment is given by

$$N_t = N_{a,t} + N_{n,t}, \tag{2.19}$$

while, aggregate employment at sectoral level is in turn given by

$$N_{s,t} \equiv \int_0^1 \int_0^1 N_{s,t}(i,j)djdi. \tag{2.20}$$

The sectoral production function is given by (derivations in Appendix A.5)

$$Y_{s,t} = A_{s,t} N_{s,t}^{1-\alpha_s} \left(\Delta_{p,t}^s \Delta_{w,t}\right)^{-(1-\alpha_s)}, \tag{2.21}$$

where the price dispersion is defined as $\Delta_{p,t}^s \equiv \int_0^1 \left(P_{s,t}(i)/P_{s,t}\right)^{\frac{-\varepsilon_p}{1-\alpha_s}} di$ and wage dispersion as $\Delta_{w,t} \equiv \int_0^1 (W_t(j)/W_t)^{-\varepsilon_w} dj$. As it is standard in the literature, the variables $\Delta_{w,t}$ and $\Delta_{p,t}^s$ are sources of inefficient output and employment variation, arising from inefficient price and wage dispersion due to nominal frictions present in the economy.

Finally, aggregate nominal output can be defined as $P_t Y_t \equiv P_{a,t} Y_{a,t} + P_{n,t} Y_{n,t}$.

2.2.5 Central Bank

The central bank sets the nominal interest rate following a simple and implementable Taylor rule, as in Schmitt-Grohe and Uribe (2006), given by

$$R_t = \frac{1}{\beta} (\frac{\Pi_t^*}{\Pi})^{\phi_\pi}, \tag{2.22}$$

where $R_t = Q_t^{-1}$ is the nominal interest rate and $\phi_\pi > 1$ is the weight assigned to the inflation target with respect to steady state, Π_t^*/Π.

The measure of inflation that the central bank targets is defined as $\Pi_t^* \equiv \Pi_{a,t}^{\Omega}\Pi_{n,t}^{1-\Omega}$, where Ω is the weight assigned to agricultural inflation, $\Pi_{a,t}$. When $\Omega = 0$ the target is interpreted as core inflation, a measure excluding flexible agricultural prices. When the weight is steady state agricultural consumption share, $\Omega = P_a C_a / PY$, the target can be interpreted as headline inflation, the broadest measure available. In the quantitative exercise below, we compute the optimal level of Ω that maximizes welfare. Note that there are three different measures of inflation: headline, core and the optimal.

2.2.6 Shocks

The model includes temporary shocks to agricultural and non-agricultural productivity. The exogenous process for sector $s \in \{a, n\}$ is given by

$$A_{s,t} = A_{s,0} e^{a_{s,t}},$$

where the shock, $a_{s,t}$, is given by

$$a_{s,t} = \rho_s a_{s,t-1} + \nu_{s,t}.$$

The variables $\nu_{a,t}$ and $\nu_{n,t}$ are IID shocks with zero mean and standard deviation σ_{va} and σ_{vn}. The parameter ρ_s indicates shock persistence. $A_{a,0}$ and $A_{n,0}$ are steady state productivity levels in agriculture and non-agriculture, respectively.

2.2.7 Welfare

To evaluate the optimal weight of agricultural inflation in the Taylor rule we introduce a welfare function. Welfare of household j is defined as

$$\mathbb{W}_t(j) \equiv \mathbb{E}_t \left\{ \sum_{k=0}^{\infty} \beta^k \left(\frac{C_{t+k}(j)^{1-\sigma}}{1-\sigma} - \frac{N_{t+k}(j)^{1+\varphi}}{1+\varphi} \right) \right\}.$$

Aggregating for all households and assuming complete markets ($C_t(j) = C_t$), it can be expressed recursively as

$$\int_0^1 \mathbb{W}_t(j)dj = \frac{C_t^{1-\sigma}}{1-\sigma} - \int_0^1 \frac{N_t(j)^{1+\varphi}}{1+\varphi}dj + \beta\mathbb{E}_t \int_0^1 \mathbb{W}_{t+1}(j)dj$$

Aggregating equation (2.3) for all firms i and using (2.19), we have that $N_t(j) = (W_t(j)/W_t)^{-\varepsilon_w} N_t$. Thus, aggregate welfare, $\mathbb{W}_t$, is given by

$$\mathbb{W}_t = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}\Delta^*_{w,t}}{1+\varphi} + \beta\mathbb{E}_t\left\{\mathbb{W}_{t+1}\right\}, \tag{2.23}$$

where $\mathbb{W}_t \equiv \int_0^1 \mathbb{W}_t(j)dj$ and $\Delta^*_{w,t} \equiv \int_0^1 (W_t(j)/W_t)^{-\varepsilon_w(1+\varphi)} dj$. Note the similarity between the wage dispersion, $\Delta_{w,t}$, and the term $\Delta^*_{w,t}$. Both of these terms reflect inefficient employment variation arising from inefficient wage dispersion. Therefore, loss due to wage dispersion arises two times in the model. First, as a result of aggregating output at sector level. Second, after aggregating welfare across households.

2.3 Quantitative exercise

2.3.1 Parameter values

We set parameters for a baseline scenario and then perform sensitivity analysis. We set $\sigma = 1$ (log utility) and $\varphi = 1$, which are common in the literature. The elasticity of substitution is set to $\gamma = 0.3$, following Ngai and Pissarides (2004). We set $\beta = 0.99$ which implies an annual interest rate of 4%. The elasticity of substitution across goods and labor varieties are set to $\varepsilon_p = \varepsilon_w = 6$, as in Blanchard and Gali (2008), implying markups of 1.2 in steady state. We set $\theta_n = 2/3$ and $\theta_w = 3/4$, implying an average price duration of three quarters, as in Blanchard and Gali (2008), and an average contract duration for wages of four quarters, as in Erceg *et al.* (2000). We set θ_a to zero, so that prices in agriculture are flexible, as argued in Bils and Klenow (2004). For simplicity, we consider linear production technologies ($\alpha_a = \alpha_n = 0$).

Using the steady state equations of the model, we calibrate the structural change parameters to match data on employment, relative prices and income for rich and developing countries. For rich countries, we set the preference parameter ω_a to 0.02 to match agricultural employment share in the U.S. ($N_a/N = 2\%$), and $A_{a,0} = A_{n,0} = 1$ to normalize income (Y) and relative agricultural prices (P_a/P) to 1. We then set the preference parameter $\tilde{C}_a$ to 0.02808 and technology parameters $A_{n,0} = 0.154$ and $A_{a,0} = 0.66 * 0.154$, to match agricultural the employment share ($N_a/N = 30\%$), income (15% of the U.S,) and relative agricultural prices (50% higher than U.S.) in a developing country.[6]

We set the response to inflation in the Taylor rule, ϕ_π, to 1.5. The productivity shock parameters are set according to Anand *et al.* (2015), that is $\rho_a = 0.25$, $\rho_n = 0.9$, $\sigma_{va} = 0.03$ and $\sigma_{vn} = 0.02$. Shocks in agriculture are assumed less persistent than in non-agriculture, which results from the dependence of the sector on weather, as argued in Anand *et al.* (2015). In the simulation exercise, Ω is computed to maximize welfare. We summarize the parameter values in Table 2.1.

2.3.2 Results

We solve the model numerically using a second-order approximation to the system of non-linear equations around its steady state. We summarize the model equations, including recursive formulations of equations (2.5) and (2.13), price dispersion ($\Delta^s_{p,t}$) and wage dispersion ($\Delta_{w,t}$) in Appendix A.6. Using the baseline parameter set up for a developing country, we compute the weight of agricultural inflation, Ω, in the Taylor rule (2.22) that maximizes welfare (2.23).

We find that the type of productivity shock hitting the economy is key to determine the optimal weight that the central bank should assign to agricultural inflation. After a shock to agricultural productivity, it is optimal for the central bank to assign full weight to non-agricultural (core) inflation ($\Omega = 0$). After a temporary shock to non-agricultural productivity, we find that the opposite is true. That is, the full weight should be allocated to agricultural inflation ($\Omega = 1$). These results are summarized in Figures 2.1 and 2.2. Furthermore, if both agricultural and non-agricultural productivity shocks occur simultaneously it is still optimal for the central bank to assign a non-zero

[6] According to Alvarez-Cuadrado and Poschke (2011), currently rich countries had higher-than-one relative prices of agricultural goods (in units of manufacturing goods) in an early stage of development.

weight to agricultural inflation. This exercise is summarized in Figure 2.3. To understand why this is the case we take a look at the impulse responses.

After an agricultural productivity shock, it is optimal to respond only to inflation in the sticky price sector. We can infer the reasoning by looking at the impulse responses in Figure 2.4. After a positive agricultural productivity shock, there is an immediate and sharp decline in agricultural inflation. This is followed by a period of positive agricultural inflation, resulting from the temporary productivity shock fading away. Headline inflation increases as well, as 35% of this aggregate index corresponds to agricultural inflation. If the central bank responds to headline inflation (the continuous line) by rising the interest rate, it destabilizes the economy. That is, we observe higher volatility in wage inflation, price inflation in the non-agricultral sector and output gap. The central bank stabilizes the economy by targeting core inflation (dashed line).

After a non-agricultural productivity shock, it is desirable to assign non-zero weight in the Taylor rule to agricultural inflation. In fact, the optimal weight is the maximum allowed ($\Omega = 1$). The reason is that the evolution of wage inflation follows closely that of agricultural inflation. This can be observed in the impulse responses in Figure 2.5. After a productivity shock in non-agriculture, both wages and non-agricultural prices are affected. It is not possible for the central bank to stabilize both variables if it reacts to non-agricultural inflation only (dashed line). However, the central bank can contain wage inflation by containing agricultural inflation (continuous line), since there is a link between these variables.

To clarify this result, we use the optimal price equation (2.5). We consider the case where only non-agricultural productivity shocks are present and technologies are linear. Then, flexible agricultural prices are given by

$$P_{a,t} = \mu_p \frac{W_t}{A_{a,0}},$$

while non-agricultural sticky prices are given by

$$P^*_{n,t} = \mu_p \frac{\sum_{k=0}^{\infty} (\theta_n)^k \mathbb{E}_t \left\{ Q_{t,t+k} Y_{n,t+k|t} \frac{W_{t+k}}{A_{n,t+k}} \right\}}{\sum_{k=0}^{\infty} (\theta_n)^k \mathbb{E}_t \left\{ Q_{t,t+k} Y_{n,t+k|t} \right\}}.$$

Note that wages in both sectors are equal and proportional to agricultural prices (since $A_{a,0}$ and μ_p are constant parameters). Therefore, if the central bank targets agricultural price inflation it can contain wage inflation. Moreover, it indirectly contains non-agricultural price inflation, as wages are part of marginal costs in this sector. Conversely, if the central bank targets core inflation (that is, sticky non-agricultural prices), it can not simultaneously contain wage inflation. Since wage inflation and non-agricultural price inflation are the main sources of welfare loss, the central bank can minimize losses by targeting agricultural inflation.

We now examine an economy with the sectoral composition of a developed country. Results show that the optimal weight of agricultural inflation remains unchanged in a rich economy with lower agricultural employment and consumption share. Figures 2.6 to 2.8 show that the optimal weights for an advanced economy are almost the same as in a developing economy. To understand these results, we compare the impulse responses between rich and developing economies after a non-agricultural productivity shock. Figure 2.9 shows impulse responses when the central bank targets core inflation, while Figure 2.10 when it assigns full weight to agricultural inflation. We consider two developing countries, one with $N_a/N = 30\%$ the other with $N_a/N = 50\%$, in addition to a rich country with $N_a/N = 2\%$. We find that the response of wage inflation and price inflation (in both sectors) is amplified in a rich country, after a productivity shock in non-agriculture. Since income and price elasticity of agricultural goods consumption is lower in developing countries, employment in this sector can not fluctuate as much as in rich countries. This explains the higher wage fluctuation in developed countries. However, this does not change the fact that it is optimal to set $\Omega = 1$ in order to reduce wage and price inflation, in both developing and rich countries.

The sectoral composition affects the welfare gain that central banks can attain by targeting the optimal measure of inflation. In panels (a) and (b) of Figure 2.11, we observe the optimal weight for agricultural inflation after non-agricultural productivity shocks. As discussed above, it is optimal to set $\Omega = 1$ in both rich and poor countries. In a developing country, targeting headline inflation (vertical dashed line) improves welfare substantially with respect to core inflation. This is not the case in rich countries where the weight of agriculture in headline inflation is small. However, notice that rich countries experience the largest gain in welfare by setting $\Omega = 1$, with respect to headline inflation targeting. In panels (c) and (d) of the same figure, we observe the opposite result after an agricultural productivity shock. In this case, it is the developing country that observes larger welfare gains after setting core inflation as the target ($\Omega = 0$), with respect to headline inflation targeting (vertical dashed line). The later result was already discussed in Portillo *et al.* (2016), the former however is new, to the best of our knowledge.

2.3.3 Role of sticky wages

In the previous subsection, we saw that setting a full weight to agricultural inflation is optimal for the central bank, after non-agricultural productivity shocks. This is a consequence of the link between agricultural prices and wages. The result is robust to changes in sectoral composition. It is however sensitive to how sticky wages are. In fact, if we reduce the parameter controlling the degree of wage stickiness (θ_w), we find that the optimal weight of agricultural inflation is reduced to a value close to zero and generates only small welfare gains compared to core inflation targeting.

To explore the link between agricultural and wage inflation further, we introduce the following modified Taylor rule

$$R_t = \frac{1}{\beta}(\frac{\Pi_t^*}{\Pi})^{\phi_\pi}(\frac{\Pi_{w,t}}{\Pi_w})^{\phi_w},$$

where $\Pi_{w,t}/\Pi_w$ indicates wage inflation in deviations from steady state and ϕ_w the weight assigned by the central bank to wage inflation. As before, the measure of inflation is given by $\Pi_t^* \equiv \Pi_{a,t}^{\Omega}\Pi_{n,t}^{1-\Omega}$. We find that the optimal weight for agricultural prices declines, in both rich and poor countries, using the modified Taylor rule. In fact, for $\phi_w \geqslant 3$, the optimal Ω is lower than 0.1 and welfare gains from setting $\Omega > 0$ are largely reduced. This supports our previous claim that targeting agricultural prices in a simple Taylor rule is a proxy for targeting wage inflation.

2.3.4 Sensitivity analysis

We perform a series of tests to check how sensitive is the optimal weight of agricultural inflation to changes in the baseline parameters. First, we test changes to parameters that determine the steady state of the model. We find that changes in the elasticity of substitution across agricultural and non-agricultural goods, γ, in the elasticity of substitution across goods and labor varieties, ε_p and ε_w, in the Frisch elasticity of labor supply, $1/\varphi$, and considering decreasing return to scale technologies $\alpha_a, \alpha_n \in \{0, 1\}$ have no effect on the optimal Ω.

Second, we test changes to the parameters underlying productivity shocks. As expected, these changes affect the optimal value of Ω. We set values for relative standard deviation σ_a/σ_n from $0.01/0.05$ to $0.05/0.01$, and values for relative autocorrelation ρ_a/ρ_n from $0.1/0.9$ to $0.7/0.3$ and compute the optimal Ω. Results are summarized in Figure 2.12. They indicate that, as the relative standard deviation and the relative autocorrelation of agricultural productivity shocks increase, the optimal weight that the central bank should assign to agricultural inflation approaches zero. That is, the central bank should assign higher weight to agricultural inflation when shocks to this sector are less persistent and of lower magnitude than in non-agriculture.

Finally, we simulate the model with flexible wages ($\theta_w = 0$), flexible agricultural prices, sticky non-agricultural prices and productivity shocks in both sectors with the same persistence and magnitude ($\rho_a/\rho_n = \sigma_a/\sigma_n = 1$). We find that the optimal Ω decreases to 0.1, a value much lower than the baseline scenario including both shocks (Figure 2.3). In this case, welfare loss due to wage dispersion is reduced. Therefore, the central bank does not need to contain wage inflation through agricultural inflation.

2.4 Welfare loss function

We derive a welfare loss function to analyze the sources of welfare loss. Since our objective is to understand why should the central bank assign non-zero weight to agricultural inflation, we simplify the model by setting γ to 1 (Cobb-Douglas case), and drop the productivity shock in the agricultural sector. In Section 2.3.4, we showed that these simplifications have no effect on the optimal Ω. To derive the welfare loss function, we take a second order approximation to the utility function and use the optimality conditions from households and firms and the market clearing conditions. We obtain the following function (derivations in Appendix A.7)

$$\begin{aligned}\mathbb{W}_0 &= -\frac{1}{2}\mathbb{E}_0\Big\{\textstyle\sum_{t=0}^{\infty}\beta^t(\psi_{ya}\tilde{y}_{a,t}^2+\psi_{yn}\tilde{y}_{n,t}^2+\psi_{\pi a}\pi_{a,t}^2+\psi_{\pi n}\pi_{n,t}^2+\psi_w\pi_{w,t}^2 \\ &\quad +\psi_p\hat{y}_{a,t}\hat{y}_{n,t})\Big\}. \end{aligned} \tag{2.24}$$

Welfare losses can be decomposed in variance of output gap in agriculture ($\tilde{y}_{a,t}^2$), output gap in non-agriculture ($\tilde{y}_{n,t}^2$), agricultural inflation ($\pi_{a,t}^2$), non-agricultural inflation ($\pi_{n,t}^2$), wage inflation ($\pi_{w,t}^2$) and the cross product of output in both sectors. We interpret (2.24) as welfare losses in units of total real expenditure, Y, that arise after a non-agricultural productivity shock. The weights of each component are given by ψ_{ya}, ψ_{yn}, $\psi_{\pi a}$, $\psi_{\pi n}$, ψ_w and ψ_p. The weights are determined by price and wage frictions parameters, sectoral composition in steady state, in addition to preference and technology parameters. Welfare losses are increasing in price and wage stickiness.

To compute welfare losses (2.24), we use a log-linear approximation to the non-linear system of equations of the model. Results are summarized in Table 2.2. When the country targets core inflation, we find that wage inflation and non-agricultural price inflation generate the bulk of welfare loss. If the central bank sets the full weight to agricultural inflation, it reduces welfare losses generated by these two components, and thus total welfare loss. This is the case in both rich and developing countries.

2.5 Concluding remarks

In this chapter, we study what is the optimal measure of inflation that a central bank should target, given the sectoral composition of the economy. The optimal measure of inflation is defined as the weights assigned to inflation in each sector, such that the central bank minimizes welfare losses that arise due to nominal frictions in the economy.

We consider a two sector model including features from the structural change and new Keynesian literature. The steady state of the model is calibrated to replicate the sectoral composition of a developing and a rich economy. We assume flexible agricultural prices and sticky non-agricultural prices and wages. In developing countries, where the agricultural consumption share is large, the aggregate price index includes a large fraction of flexible agricultural prices.

The model shows that the type of shock hitting the economy is key to determine the optimal weight of agricultural inflation. When only agricultural productivity shocks are present, it is optimal to target core inflation, that is non-agricultural sticky prices. This result holds independently of how sticky wages are. On the other hand, when only non-agricultural productivity shocks are present and wages are sticky, it is optimal to assign full weight to flexible agricultural prices. If the central bank contains agricultural inflation it can contain wage inflation, since agricultural prices are proportional to marginal costs and, therefore, wages. Since wages are equal in both sectors, by containing wage inflation, the central bank indirectly contains non-agricultural prices through marginal costs. Therefore, the central bank can reduce wage inflation and non-agricultural price inflation, the two main sources of welfare loss, using agricultural inflation as a proxy of wage inflation.

When the sectoral composition changes, the optimal weight remains unchanged. The reason is that, as long as wages are sticky and equal across sectors, the central bank can always reduce welfare loss arising from inefficient wage dispersion by containing agricultural prices. In addition, we find that changes in sectoral composition due to structural change have important consequences for welfare, when the central bank targets the optimal measure of inflation. Developing countries experience larger welfare gain by targeting core inflation after agricultural productivity shocks. Rich countries, on the other hand, experience larger welfare gain by fully targeting agricultural inflation after non-agricultural productivity shocks, which is equivalent to targeting wage inflation.

Finally, we acknowledge that the results in this chapter depend on our assumptions of equal degree of wage stickiness across sectors, free labor mobility across sectors, and the shock parameters. Future work will include investigating the effects of different degree of wage stickiness across sectors, including imperfect labor mobility, and providing further empirical support to the shock structure in developing countries.

Appendix A. Derivations

A.1. Firm's cost minimization

We derive labor demand equation (2.3). A firm i in sector s solves the following minimization problem

$$\min_{N_{s,t}(i,j)} \int_0^1 W_t(j) N_{s,t}(i,j) dj - \lambda [A_{s,t} N_{s,t}(i)^{1-\alpha_s} - Y_{s,t}(i)]$$

subject to (2.2). First order conditions for labor variety j imply

$$W_t(j) = \lambda(1-\alpha_s) A_{s,t} \left(\int_0^1 N_{s,t}(i,j)^{\frac{\varepsilon_w - 1}{\varepsilon_w}} dj \right)^{\frac{\varepsilon_w(1-\alpha_s)}{\varepsilon_w - 1} - 1} N_{s,t}(i,j)^{\frac{-1}{\varepsilon_w}},$$

combining optimality conditions for labor variety j and j' in sector s, we obtain

$$N_{s,t}(i,j) = N_{s,t}(i,j')(\frac{W_t(j)}{W_t(j')})^{-\varepsilon_w},$$

plugging this expression in (2.2), we obtain equation (2.3) as

$$N_{s,t}(i,j) = (\frac{W_t(j)}{W_t})^{-\varepsilon_w} N_{s,t}(i)$$

where the wage index W_t is defined by equation (2.4).

A.2 Demand constraint in the optimal price and wage setting problem

The demand constraint for sector s in the optimal price setting problem results from aggregating demand equation (2.6) for all households j as

$$\int_0^1 C_{s,t}(i,j)dj = \left(\frac{P_{s,t}(i)}{P_{s,t}}\right)^{-\varepsilon_p} \int_0^1 C_{s,t}(j)dj.$$

Using marketing clearing conditions (2.17) and (2.18) we obtain the demand constraint as

$$Y_{s,t}(i) = \left(\frac{P_{s,t}(i)}{P_{s,t}}\right)^{-\varepsilon_p} C_{s,t}.$$

The labor demand constraint in the optimal wage setting problem results from integrating equation (2.3) with respect to i as

$$\int_0^1 N_{s,t}(i,j)di = \left(\frac{W_t(j)}{W_t}\right)^{-\varepsilon_w} \int_0^1 N_{s,t}(i)di,$$

where $\int_0^1 N_{s,t}(i,j)di = N_{s,t}(j)$ is employment of labor variety j by all firms in sector s and $\int_0^1 N_{s,t}(i)di = N_{s,t}$ is aggregate employment at sectoral level. Therefore $N_{s,t}(j) = (W_t(j)/W_t)^{-\varepsilon_w} N_{s,t}$. Adding up this expression for both sectors, we obtain demand for labor variety j as

$$\begin{aligned} N_t(j) &= N_{a,t}(j) + N_{n,t}(j) \\ &= \left(\frac{W_t(j)}{W_t}\right)^{-\varepsilon_w} (N_{a,t} + N_{n,t}) \\ &= \left(\frac{W_t(j)}{W_t}\right)^{-\varepsilon_w} N_t. \end{aligned}$$

A.3 Optimal consumption allocation of household j

We derive household demand equations (2.6) for sector s. Household j maximizes $C_t(j)$ conditional on expenditure level E_t in every period t as

$$\max_{\{C_{a,t}(i,j),C_{n,t}(i,j)\}_{i\in(0,1)}} \Big\{\omega_a^{\frac{1}{\gamma}}\Big[\Big(\int_0^1 C_{a,t}(i,j)^{\frac{\varepsilon p-1}{\varepsilon p}}di\Big)^{\frac{\varepsilon}{\varepsilon-1}} - \tilde{C}_a\Big]^{\frac{\gamma-1}{\gamma}} + \omega_n^{\frac{1}{\gamma}}\Big[\Big(\int_0^1 C_{n,t}(i,j)^{\frac{\varepsilon p-1}{\varepsilon p}}di\Big)^{\frac{\varepsilon}{\varepsilon-1}}\Big]^{\frac{\gamma-1}{\gamma}}\Big\}^{\frac{\gamma}{\gamma-1}} - \lambda\Big(\int_0^1 P_{a,t}(i)C_{a,t}(i,j)di + \int_0^1 P_{n,t}(i)C_{n,t}(i,j)di - E_t(j)\Big).$$

First order conditions for good i in sectors a and n imply

$$C_t(j)^{\frac{1}{\gamma}}\omega_a^{\frac{1}{\gamma}}[C_{a,t}(j)-\tilde{C}_a]^{\frac{-1}{\gamma}}C_{a,t}(j)^{\frac{1}{\varepsilon p}}C_{a,t}(i,j)^{\frac{-1}{\varepsilon p}} = \lambda P_{a,t}(i) \tag{2.25}$$

and

$$C_t(j)^{\frac{1}{\gamma}}\omega_n^{\frac{1}{\gamma}}C_{n,t}(j)^{\frac{-1}{\gamma}}C_{n,t}(j)^{\frac{1}{\varepsilon p}}C_{n,t}(i,j)^{\frac{-1}{\varepsilon p}} = \lambda P_{n,t}(i). \tag{2.26}$$

Combining the first order conditions for good i and i' in sector s, we obtain

$$\frac{C_{s,t}(i,j)}{C_{s,t}(i',j)} = (\frac{P_{s,t}(i)}{P_{s,t}(i')})^{-\varepsilon_p},$$

combining this last equation with the definition of $C_{s,t}(j)$, we obtain equation (2.6) as

$$C_{s,t}(i,j) = C_{s,t}(j)(\frac{P_{s,t}(i)}{P_{s,t}})^{-\varepsilon_p}$$

where the relative price $P_{s,t}$ is given by equation (2.7). Finally, combining (2.6), (2.25) and (2.26) we obtain equation (2.8).

A.4 Sectoral demand

We derive household demand equations (2.9) and (2.10). First, we define total expenditure, $E_t(j) \equiv P_{a,t}C_{a,t}(j) + P_{n,t}C_{n,t}(j)$. Plugging equation (2.8) into this definition, we obtain

$$C_{n,t}(j) = \omega_n(\frac{P_{n,t}}{P_t})^{1-\gamma}\frac{E_t(j) - P_{a,t}\tilde{C}_a}{P_{n,t}} \tag{2.27}$$

and

$$C_{a,t}(j) - \tilde{C}_a = \omega_a(\frac{P_{a,t}}{P_t})^{1-\gamma}\frac{E_t(j) - P_{a,t}\tilde{C}_a}{P_{a,t}} \tag{2.28}$$

where the price index P_t is defined in equation (2.11). Plugging (2.27) and (2.28) into the definition of $C_t(j)$ we obtain

$$P_tC_t(j) = E_t(j) - P_{a,t}\tilde{C}_a. \tag{2.29}$$

Combining equations (2.27) and (2.28) with (2.29), we obtain household demand equations (2.9) and (2.10).

A.5 Sectoral production function

The sectoral production function can be obtain combining equations (2.3) and (2.20) as

$$\begin{aligned} N_{s,t} &\equiv \int_0^1 \int_0^1 N_{s,t}(i,j)dj di \\ &= \int_0^1 \int_0^1 \left(\frac{W_t(j)}{W_t}\right)^{-\varepsilon_w} N_{s,t}(i) dj di \\ &= \Delta_{w,t} \int_0^1 N_{s,t}(i) di \end{aligned}$$

where $\Delta_{w,t} \equiv \int_0^1 \left(\frac{W_t(j)}{W_t}\right)^{-\varepsilon_w} dj$. Using equations (2.1), (2.6), (2.17) and (2.18), we obtain equation (2.21) as

$$\begin{aligned} N_{s,t} &= \Delta_{w,t} \frac{1}{A_{s,t}^{\frac{1}{1-\alpha_s}}} \int_0^1 Y_{s,t}(i)^{\frac{1}{1-\alpha_s}} di \\ &= \Delta_{w,t} \frac{1}{A_{s,t}^{\frac{1}{1-\alpha_s}}} \int_0^1 \left(\int_0^1 C_{s,t}(i,j)dj\right)^{\frac{1}{1-\alpha_s}} di \\ &= \Delta_{p,t}^s \Delta_{w,t} \left(\frac{Y_{s,t}}{A_{s,t}}\right)^{\frac{1}{1-\alpha_s}}, \end{aligned}$$

where $\Delta_{p,t}^s \equiv \int_0^1 \left(\frac{P_{s,t}(i)}{P_{s,t}}\right)^{\frac{-\varepsilon_p}{1-\alpha_s}} di$. Rearranging the last equality we obtain expression (2.21).

A.6 System of non-linear equations

The system of nonlinear equations of the model is given by

Demand equations:

$$Q_t = \beta \mathbb{E}_t \left\{ \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{1}{\Pi_{t+1}} \right\}$$

$$C_{n,t} = \omega_n (P_{n,t}/P_t)^{-\gamma} C_t$$

$$C_{a,t} = \tilde{C}_a + \omega_a (P_{a,t}/P_t)^{-\gamma} C_t$$

Price equations:

$$1 = \omega_a (P_{a,t}/P_t)^{1-\gamma} + \omega_n (P_{n,t}/P_t)^{1-\gamma}$$

$$1 = \theta_a \Pi_{a,t}^{\varepsilon_p - 1} + (1-\theta_a) \left(\frac{P^*_{a,t}/P_t}{P_{a,t}/P_t} \right)^{1-\varepsilon_p}$$

$$1 = \theta_n \Pi_{n,t}^{\varepsilon_p - 1} + (1-\theta_n) \left(\frac{P^*_{n,t}/P_t}{P_{n,t}/P_t} \right)^{1-\varepsilon_p}$$

$$1 = \theta_w \Pi_{w,t}^{\varepsilon_w - 1} + (1-\theta_w) \left(\frac{W^*_t/P_t}{W_t/P_t} \right)^{1-\varepsilon_w}$$

Market clearing:

$$Y_{a,t} = C_{a,t}$$

$$Y_{n,t} = C_{n,t}$$

$$N_t = N_{a,t} + N_{n,t}$$

$$N_{a,t} = \Delta_{w,t} \Delta^a_{p,t} \left(\frac{Y_{a,t}}{A_{a,t}} \right)^{\frac{1}{1-\alpha_a}}$$

$$N_{n,t} = \Delta_{w,t} \Delta^n_{p,t} \left(\frac{Y_{n,t}}{A_{n,t}} \right)^{\frac{1}{1-\alpha_n}}$$

Price setting:

$$\kappa^a_{1,t} = Y_{a,t} \left(\frac{P^*_{a,t}/P_t}{P_{a,t}/P_t} \right)^{-\varepsilon_p} + \theta_a \mathbb{E}_t Q_t \left(\frac{P^*_{a,t}/P_t}{P^*_{a,t+1}/P_{t+1}} \frac{1}{\Pi_{t+1}} \right)^{-\varepsilon_p} \kappa^a_{1,t+1}$$

$$\kappa_{2,t}^a = Y_{a,t} MC_{a,t} \left(\frac{P_{a,t}^*/P_t}{P_{a,t}/P_t} \right)^{-\frac{1-\alpha_a+\varepsilon_p}{1-\alpha_a}} +$$

$$\theta_a \mathbb{E}_t Q_t \left(\frac{P_{a,t}^*/P_t}{P_{a,t+1}^*/P_{t+1}} \frac{1}{\Pi_{t+1}} \right)^{-\frac{1-\alpha_a+\varepsilon_p}{1-\alpha_a}} \kappa_{2,t+1}^a$$

$$\kappa_{1,t}^a = \mu_p \kappa_{2,t}^a$$

$$\kappa_{1,t}^n = Y_{n,t} \left(\frac{P_{n,t}^*/P_t}{P_{n,t}/P_t} \right)^{-\varepsilon_p} + \theta_n \mathbb{E}_t Q_t \left(\frac{P_{n,t}^*/P_t}{P_{n,t+1}^*/P_{t+1}} \frac{1}{\Pi_{t+1}} \right)^{-\varepsilon_p} \kappa_{1,t+1}^n$$

$$\kappa_{2,t}^n = Y_{n,t} MC_{n,t} \left(\frac{P_{n,t}^*/P_t}{P_{n,t}/P_t} \right)^{-\frac{1-\alpha_n+\varepsilon_p}{1-\alpha_n}} +$$

$$\theta_n \mathbb{E}_t Q_t \left(\frac{P_{n,t}^*/P_t}{P_{n,t+1}^*/P_{t+1}} \frac{1}{\Pi_{t+1}} \right)^{-\frac{1-\alpha_n+\varepsilon_p}{1-\alpha_n}} \kappa_{2,t+1}^n$$

$$\kappa_{1,t}^n = \mu_p \kappa_{2,t}^n$$

Wage setting:

$$\kappa_{1,t}^w = C_t^{-\sigma} N_t \left(\frac{W_t^*/P_t}{W_t/P_t} \right)^{-\varepsilon_w} W_t^*/P_t + (\theta_w \beta) \mathbb{E}_t \left(\frac{W_t^*/P_t}{W_{t+1}^*/P_{t+1}} \frac{1}{\Pi_{t+1}} \right)^{1-\varepsilon_w} \kappa_{1,t+1}^w$$

$$\kappa_{2,t}^w = C_t^{-\sigma} N_t MRS_t \left(\frac{W_t^*/P_t}{W_t/P_t} \right)^{-\varepsilon_w(1+\varphi)} +$$

$$(\theta_w \beta) \mathbb{E}_t \left(\frac{W_t^*/P_t}{W_{t+1}^*/P_{t+1}} \frac{1}{\Pi_{t+1}} \right)^{-\varepsilon_w(1+\varphi)} \kappa_{2,t+1}^w$$

$$\kappa_{1,t}^w = \mu_w \kappa_{2,t}^w$$

Price and wage dispersion:

$$\Delta_{p,t}^a = (1-\theta_a) \left(\frac{P_{a,t}^*/P_t}{P_{a,t}/P_t} \right)^{\frac{-\varepsilon_p}{1-\alpha_a}} + \theta_a \Pi_{a,t}^{\frac{\varepsilon_p}{1-\alpha_a}} \Delta_{p,t-1}^a$$

$$\Delta_{p,t}^{n} = (1-\theta_n)\left(\frac{P_{n,t}^{*}/P_t}{P_{n,t}/P_t}\right)^{\frac{-\varepsilon p}{1-\alpha n}} + \theta_n \Pi_{n,t}^{\frac{\varepsilon p}{1-\alpha n}} \Delta_{p,t-1}^{n}$$

$$\Delta_{w,t} = (1-\theta_w)\left(\frac{W_t^{*}/P_t}{W_t/P_t}\right)^{-\varepsilon_w} + \theta_w \Pi_{w,t}^{\varepsilon_w} \Delta_{w,t-1}$$

Sectoral inflation, wage inflation, marginal costs, and marginal rate of substitution:

$$\Pi_{a,t} = \frac{P_{a,t}/P_t}{P_{a,t-1}/P_{t-1}} \Pi_t$$

$$\Pi_{n,t} = \frac{P_{n,t}/P_t}{P_{n,t-1}/P_{t-1}} \Pi_t$$

$$\Pi_{w,t} = \frac{W_t/P_t}{W_{t-1}/P_{t-1}} \Pi_t$$

$$MC_{a,t} = \frac{1}{1-\alpha_a} \frac{W_t/P_t}{P_{a,t}/P_t} \frac{N_{a,t}}{Y_{a,t}}$$

$$MC_{n,t} = \frac{1}{1-\alpha_n} \frac{W_t/P_{n,t}}{P_{n,t}/P_t} \frac{N_{n,t}}{Y_{n,t}}$$

$$MRS_t = C_t^{\sigma} N_t^{\varphi}$$

Taylor rule:

$$\frac{1}{Q_t} = \frac{1}{\beta} (\Pi_t^{*}/\Pi)^{\phi_\pi}$$

$$\Pi_t^{*} = \Pi_{a,t}^{\Omega} \Pi_{n,t}^{1-\Omega}$$

Aggregate output:

$$Y_t = (P_{a,t}/P_t) Y_{a,t} + (P_{n,t}/P_t) Y_{n,t}$$

Shocks:

$$\ln A_{a,t} = \ln A_{a,0} + a_{a,t}$$

$$\ln A_{n,t} = \ln A_{n,0} + a_{n,t}$$

$$a_{a,t} = \rho_a a_{a,t-1} + \nu_{a,t}$$

$$a_{n,t} = \rho_n a_{n,t-1} + \nu_{n,t}$$

A.7 Welfare loss function

We derive a second order approximation to households' welfare, following essentially the same procedure described in Gali (2008). We simplify the model and consider $\sigma = 1$ (log utility), $\alpha_a = \alpha_n = 0$ and $\gamma = 1$. Therefore, household j utility at time t is given by

$$U(C_t(j), N_t(j)) = \ln C_t(j) - \frac{N_t(j)^{1-\varphi}}{1-\varphi},$$

where $C_t(j) = \omega_a^{-\omega_a}(1-\omega_a)^{-(1-\omega_a)}(C_{a,t}(j) - \tilde{C}_a)^{\omega_a} C_{n,t}(j)^{(1-\omega_a)}$. The term $\omega_a^{-\omega_a}(1-\omega_a)^{-(1-\omega_a)}$ is introduced to reduce notation. We aggregate utility across households and take a second order Taylor expansion of the utility, U_t, around its steady state, U, to obtain the following expression

$$\begin{aligned}
\int_0^1 (U_t - U)dj \approx\ & \frac{P_a C_a}{PC}\left(\frac{C_{a,t} - C_a}{C_a}\right) - \frac{1}{2\omega_a}\left(\frac{P_a C_a}{PC}\right)^2 \left(\frac{C_{a,t} - C_a}{C_a}\right)^2 \\
& + \frac{P_n C_n}{PC}\left(\frac{C_{n,t} - C_n}{C_n}\right) - \frac{1}{2}\frac{P_n C_n}{PC}\left(\frac{C_{n,t} - C_n}{C_n}\right)^2 \\
& + \frac{P_a C_a}{PC}\frac{P_n C_n}{PC}\left(\frac{C_{a,t} - C_a}{C_a}\right)\left(\frac{C_{n,t} - C_n}{C_n}\right) \\
& + U_n N \frac{N_a}{N}\int_0^1 \frac{N_{a,t}(j) - N_a}{N_a} dj + U_n N \frac{N_n}{N}\int_0^1 \frac{N_{n,t}(j) - N_n}{N_n} dj \\
& + \frac{1}{2} U_{nn} N^2 \int_0^1 \left(\frac{N_t(j) - N}{N}\right)^2 dj. \qquad (2.30)
\end{aligned}$$

We consider the second order approximation given by $\frac{Z_t - Z}{Z} \approx \hat{z}_t + \frac{1}{2}\hat{z}_t^2$, where $\hat{z}_t$ indicates the log deviation of variable Z_t from its steady state Z. In addition, we use the market clearing condition $\hat{c}_{s,t} = \hat{y}_{s,t}$, for $s \in \{a, n\}$, to express equation (2.30) in log deviations as

$$\begin{aligned}
\int_0^1 (U_t - U)dj \approx\ & \frac{P_a C_a}{PC}\hat{y}_{a,t} + \frac{1}{2}\left(\frac{P_a C_a}{PC} - \frac{1}{\omega_a}\left(\frac{P_a C_a}{PC}\right)^2\right)\hat{y}_{a,t}^2 \\
& + \frac{P_n C_n}{PC}\hat{y}_{n,t} + \frac{P_a C_a}{PC}\frac{P_n C_n}{PC}(\hat{y}_{a,t}\hat{y}_{n,t}) \\
& + U_n N \int_0^1 \begin{pmatrix} \frac{N_a}{N}\left(\hat{n}_{a,t}(j) + \frac{1}{2}\hat{n}_{a,t}(j)^2\right) \\ + \frac{N_n}{N}\left(\hat{n}_{n,t}(j) + \frac{1}{2}\hat{n}_{n,t}(j)^2\right) + \frac{\varphi}{2}\hat{n}_t(j)^2 \end{pmatrix} dj, \qquad (2.31)
\end{aligned}$$

where $\varphi = \frac{U_{nn}N}{U_n}$. Note that we discard terms of order higher than 2.

First, we focus on the last part of the previous equation that includes employment. Notice that the definition of aggregate employment at the sectoral level, $N_{s,t} \equiv \int_0^1 N_{s,t}(j)dj$ for $s \in \{a,n\}$, can be expressed in terms of log deviation from steady state as $\hat{n}_{s,t} + \frac{1}{2}\hat{n}_{s,t}^2 = \int_0^1 \hat{n}_{s,t}(j)dj + \frac{1}{2}\int_0^1 \hat{n}_{s,t}(j)^2 dj$. Additionally, aggregate total employment, $N_t \equiv \int_0^1 N_t(j)dj$, can be expressed in terms of log deviation from steady state as

$$\begin{aligned}
\int_0^1 \hat{n}_t(j)^2 &= \int_0^1 (\hat{n}_t(j) - \hat{n}_t + \hat{n}_t)^2 dj \\
&= \int_0^1 (-\epsilon_w(w_t(j) - w_t) + \hat{n}_t)^2 dj \\
&= \hat{n}_t^2 - 2\hat{n}_t\epsilon_w \int_0^1 (w_t(j) - w_t)dj + \epsilon_w^2 \int_0^1 (w_t(j) - w_t)^2 dj \\
&= \hat{n}_t^2 + \epsilon_w^2 \int_0^1 (w_t(j) - w_t)^2 dj \\
&= \hat{n}_t^2 + \epsilon_w^2 var_j\{w_t(j)\}, \qquad (2.32)
\end{aligned}$$

where we use the labor demand equation expressed in deviation from steady state, $\hat{n}_t(j) = \hat{n}_t - \epsilon_w(w_t(j) - w_t)$. Following Gali (2008), we consider that $\int_0^1 (w_t(j) - w_t)^2 dj \simeq \int_0^1 (w_t(j) - E_j\{w_t(j)\})^2 dj \equiv var_j\{w_t(j)\}$ holds up to a second order approximation. We discard the term $2\hat{n}_t\epsilon_w \int_0^1 (w_t(j) - w_t)\, dj = 2\hat{n}_t\epsilon_w \frac{(\epsilon_w - 1)}{2} var_j\{w_t(j)\}$ since it of order higher than two. Replacing in equation (2.31), we have

$$\begin{aligned}
\int_0^1 (U_t - U)dj &= \frac{P_aC_a}{PC}\hat{y}_{a,t} + \frac{1}{2}\left(\frac{P_aC_a}{PC} - \frac{1}{\omega_a}\left(\frac{P_aC_a}{PC}\right)^2\right)\hat{y}_{a,t}^2 \\
&+ \frac{P_nC_n}{PC}\hat{y}_{n,t} + \frac{P_aC_a}{PC}\frac{P_nC_n}{PC}(\hat{y}_{a,t}\hat{y}_{n,t}) \\
&+ U_nN\begin{pmatrix} \frac{N_a}{N}\left(\hat{n}_{a,t} + \frac{1}{2}\hat{n}_{a,t}^2\right) + \frac{N_n}{N}\left(\hat{n}_{n,t} + \frac{1}{2}\hat{n}_{n,t}^2\right) \\ + \frac{\varphi}{2}\left(\hat{n}_t^2 + \epsilon_w^2 var\{w_t(j)\}\right) \end{pmatrix}. \qquad (2.33)
\end{aligned}$$

Using a second order approximation of aggregate output at sectoral level (2.21) we obtain

$$\hat{n}_{s,t} = \hat{y}_{s,t} - a_{s,t} + d_{w,t} + d_{s,t}, \qquad (2.34)$$

where, as shown in Gali (2008), $d_{s,t} \equiv log \int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon_s} di \simeq \frac{\epsilon_p}{2} var_i \left\{p_{s,t}(i)\right\}$, $d_{w,t} \equiv log \int_0^1 \left(\frac{W_t(j)}{W_t}\right)^{-\epsilon_w} dj \simeq \frac{\epsilon_w}{2} var_j \{w_t(j)\}$. We can combine (2.34) with the expression for aggregate employment, $\hat{n}_t = \frac{N_a}{N}\hat{n}_{a,t} + \frac{N_n}{N}\hat{n}_{n,t}$, and use $\gamma_a = \frac{N_a}{N}$ and $\gamma_n = \frac{N_n}{N}$, to obtain

$$\begin{aligned}
\hat{n}_t^2 &= (\gamma_a \hat{n}_{a,t} + \gamma_n \hat{n}_{n,t})^2 \\
&= \gamma_a^2 \hat{n}_{a,t}^2 + \gamma_n^2 \hat{n}_{n,t}^2 + 2\gamma_a\gamma_n \hat{n}_{a,t}\hat{n}_{n,t}^2 \\
&= \gamma_a^2(\hat{y}_{a,t} - a_{a,t})^2 + \gamma_n^2(\hat{y}_{n,t} - a_{n,t})^2 + 2\gamma_a\gamma_n \hat{y}_{a,t}\hat{y}_{n,t},
\end{aligned}$$

where the terms of order higher than 2 are discarded. Replacing in equation (2.33), we obtain

$$\begin{aligned}
\int_0^1 (U_t - U) dj = {} & \frac{P_a C_a}{PC}\hat{y}_{a,t} + \frac{1}{2}\left(\frac{P_a C_a}{PC} - \frac{1}{\omega_a}\left(\frac{P_a C_a}{PC}\right)^2\right)\hat{y}_{a,t}^2 \\
& + \frac{P_n C_n}{PC}\hat{y}_{n,t} + \frac{P_a C_a}{PC}\frac{P_n C_n}{PC}(\hat{y}_{a,t}\hat{y}_{n,t}) \\
& + U_n N\Big[\gamma_a(\hat{y}_{a,t} + \frac{\epsilon_w}{2} var_j\{w_t(j)\} + \frac{\epsilon_p}{2} var_i\left\{p_{a,t}(i)\right\} \\
& + \frac{1}{2}(\hat{y}_{a,t} - a_{a,t})^2) + \gamma_n(\hat{y}_{n,t} + \frac{\epsilon_w}{2} var_j\{w_t(j)\} \\
& + \frac{\epsilon_p}{2} var_i\left\{p_{n,t}(i)\right\} + \frac{1}{2}(\hat{y}_{n,t} - a_{n,t})^2) \\
& + \frac{\varphi}{2}(\gamma_a^2(\hat{y}_{a,t} - a_{a,t})^2 + \gamma_n^2(\hat{y}_{n,t} - a_{n,t})^2 \\
& + 2\gamma_a\gamma_n\hat{y}_{a,t}\hat{y}_{n,t} + \epsilon_w^2 var_j\{w_t(j)\})\Big]. \qquad (2.35)
\end{aligned}$$

Using the following steady state relations $U_n N \frac{N_a}{N} = -\frac{P_a C_a}{PC}$, $U_n N \frac{N_n}{N} = -\frac{P_n C_n}{PC}$, $\frac{1}{\omega_a}\frac{P_a}{P} = \left(\frac{C_a - \tilde{C}_a}{C}\right)^{-1}$, and assuming productivity shocks to non-agriculture only, equation (2.35) can be expressed as

$$
\begin{aligned}
\int_0^1 (U_t - U)dj =& \frac{1}{2}\left(\frac{P_a}{P}\chi_a^{-1} - \beta_a^{-1}\frac{P_a}{P}\right)\chi_a^2 \hat{y}_{a,t}^2 - \frac{1}{2}\left(\frac{P_a}{P}\chi_a + \frac{P_a}{P}\chi_a\gamma_a\varphi\right)\hat{y}_{a,t}^2 \\
& - \frac{1}{2}\left(\frac{P_n}{P}\beta_n + \frac{P_n}{P}\beta_n\varphi\gamma_n\right)(\hat{y}_{n,t} - a_{n,t})^2 + \\
& \left(\frac{P_a}{P}\chi_a\frac{P_n}{P}\beta_n - \frac{P_a}{P}\chi_a\varphi\gamma_n\right)\hat{y}_{a,t}\hat{y}_{n,t} \\
& - \frac{P_a C_a}{PC}\frac{\epsilon_p}{2} var_i\left\{p_{a,t}(i)\right\} - \frac{P_n C_n}{PC}\frac{\epsilon_p}{2} var_i\left\{p_{n,t}(i)\right\} \\
& - \frac{\epsilon_w}{2}\left(\frac{P_a C_a + P_n C_n}{PC} + N^{1+\varphi}\varphi\epsilon_w\right) var_j\left\{w_t(j)\right\} \\
=& -\frac{1}{2}\left(\beta_a^{-1}\frac{P_a}{P}\chi_a^2 + \frac{P_a}{P}\chi_a\gamma_a\varphi\right)\hat{y}_{a,t}^2 \\
& - \frac{1}{2}\left\{\left(\frac{P_n}{P}\beta_n + \frac{P_n}{P}\beta_n\varphi\gamma_n\right)\hat{y}_{n,t}^2 - 2\left(\frac{P_n}{P}\beta_n + \frac{P_n}{P}\beta_n\varphi\gamma_n\right)\hat{y}_{n,t}a_{n,t}\right\} \\
& + \left(\frac{P_a}{P}\chi_a\frac{P_n}{P}\beta_n - \frac{P_a}{P}\chi_a\varphi\gamma_n\right)\hat{y}_{a,t}\hat{y}_{n,t} - \frac{P_a C_a}{PC}\frac{\epsilon_p}{2} var_i\left\{p_{a,t}(i)\right\} \\
& - \frac{P_n C_n}{PC}\frac{\epsilon_p}{2} var_i\left\{p_{n,t}(i)\right\} \\
& - \frac{\epsilon_w}{2}\left(\frac{P_a C_a + P_n C_n}{PC} + N^{1+\varphi}\varphi\epsilon_w\right) var_j\left\{w_t(j)\right\} \\
=& -\frac{1}{2}\left(\beta_a^{-1}\frac{P_a}{P}\chi_a^2 + \frac{P_a}{P}\chi_a\gamma_a\varphi\right)\hat{y}_{a,t}^2 \\
& - \frac{1}{2}\left(\frac{P_n}{P}\beta_n + \frac{P_n}{P}\beta_n\varphi\gamma_n\right)\left(\hat{y}_{n,t}^2 - 2\hat{y}_{n,t}\hat{y}_{n,t}^n\right) \\
& + \left(\frac{P_a}{P}\chi_a\frac{P_n}{P}\beta_n - \frac{P_a}{P}\chi_a\varphi\gamma_n\right)\hat{y}_{a,t}\hat{y}_{n,t} - \frac{P_a C_a}{PC}\frac{\epsilon_p}{2} var_i\left\{p_{a,t}(i)\right\} \\
& - \frac{P_n C_n}{PC}\frac{\epsilon_p}{2} var_i\left\{p_{n,t}(i)\right\} \\
& - \frac{\epsilon_w}{2}\left(\frac{P_a C_a + P_n C_n}{PC} + N^{1+\varphi}\varphi\epsilon_w\right) var_j\left\{w_t(j)\right\}
\end{aligned}
$$

where $\beta_n = \frac{C_n}{C}$, $\chi_a = \frac{C_a}{C}$ and $\beta_a = \frac{C_a - \tilde{C}_a}{C}$. $\hat{y}_{s,t}^n$ indicates natural output in sector s (that is, output in absence of nominal frictions) in deviation from steady state. Denoting sectoral output in deviation from natural level as $\tilde{y}_{s,t} =$

$\hat{y}^n_{s,t} - \hat{y}^n_{s,t}$, we obtain

$$\int_0^1 (U_t - U)dj = -\frac{1}{2}\left(\beta_a^{-1}\frac{P_a}{P}\chi_a^2 + \frac{P_a}{P}\chi_a\gamma_a\varphi\right)\tilde{y}^2_{a,t} - \frac{1}{2}\left(\frac{P_n}{P}\beta_n + \frac{P_n}{P}\beta_n\varphi\gamma_n\right)\tilde{y}^2_{n,t}$$
$$+\left(\frac{P_a}{P}\chi_a\frac{P_n}{P}\beta_n - \frac{P_a}{P}\chi_a\varphi\gamma_n\right)\hat{y}_{a,t}\hat{y}_{n,t} - \frac{P_aC_a}{PC}\frac{\epsilon_p}{2}var_i\left\{p_{a,t}(i)\right\}$$
$$-\frac{P_nC_n}{PC}\frac{\epsilon_p}{2}var_i\left\{p_{n,t}(i)\right\}$$
$$-\frac{\epsilon_w}{2}\left(\frac{P_aC_a + P_nC_n}{PC} + N^{1+\varphi}\varphi\epsilon_w\right)var_j\left\{w_t(j)\right\},$$

where the last equations results from $\hat{y}^n_{a,t} = 0$ (we consider shocks to non-agriculture only) which implies $\tilde{y}^2_{a,t} = \hat{y}^2_{a,t}$. The households' welfare loss can therefore be expressed as

$$\mathbb{E}_0 \sum\nolimits_{t=0}^{\infty} \beta^t \int_0^1 (U_t - U)dj =$$
$$-\frac{1}{2}\mathbb{E}_0 \sum\nolimits_{t=0}^{\infty} \beta^t \left\{ \begin{array}{c} \left(\beta_a^{-1}\frac{P_a}{P}\chi_a^2 + \frac{P_a}{P}\chi_a\gamma_a\varphi\right)\tilde{y}^2_{a,t} + \left(\frac{P_n}{P}\beta_n + \frac{P_n}{P}\beta_n\varphi\gamma_n\right)\tilde{y}^2_{n,t} \\ -2\left(\frac{P_a}{P}\chi_a\frac{P_n}{P}\beta_n - \frac{P_a}{P}\chi_a\varphi\gamma_n\right)\hat{y}_{a,t}\hat{y}_{n,t} \\ +\frac{P_aC_a}{PC}\epsilon_p var_i\left\{p_{a,t}(i)\right\} + \frac{P_nC_n}{PC}\epsilon_p var_i\left\{p_{n,t}(i)\right\} \\ +\epsilon_w\left(\frac{P_aC_a+P_nC_n}{PC} + N^{1+\varphi}\varphi\epsilon_w\right)var_j\left\{w_t(j)\right\} \end{array} \right\}.$$

As shown in Woodford (2003)

$$\begin{aligned} \sum\nolimits_{t=0}^{\infty}\beta^t var_i\left\{p_{a,t}(i)\right\} &= \frac{\theta_{pa}}{(1-\beta\theta_{pa})(1-\theta_{pa})}\sum\nolimits_{t=0}^{\infty}\beta^t\pi^2_{a,t}, \\ \sum\nolimits_{t=0}^{\infty}\beta^t var_i\left\{p_{n,t}(i)\right\} &= \frac{\theta_{pn}}{(1-\beta\theta_{pn})(1-\theta_{pn})}\sum\nolimits_{t=0}^{\infty}\beta^t\pi^2_{n,t}, \\ \sum\nolimits_{t=0}^{\infty}\beta^t var_j\left\{w_t(j)\right\} &= \frac{\theta_w}{(1-\beta\theta_w)(1-\theta_w)}\sum\nolimits_{t=0}^{\infty}\beta^t\pi^2_{w,t}, \qquad (2.36) \end{aligned}$$

then we have

$$
\begin{aligned}
&\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \int_0^1 (U_t - U) dj = \\
&-\frac{1}{2}\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \begin{array}{c}
\left(\beta_a^{-1}\frac{P_a}{P}\chi_a^2 + \frac{P_a}{P}\chi_a\gamma_a\varphi\right)\tilde{y}_{a,t}^2 + \left(\frac{P_n}{P}\beta_n + \frac{P_n}{P}\beta_n\varphi\gamma_n\right)\tilde{y}_{n,t}^2 \\
-2\left(\frac{P_a}{P}\chi_a\frac{P_n}{P}\beta_n - \frac{P_a}{P}\chi_a\varphi\gamma_n\right)\hat{y}_{a,t}\hat{y}_{n,t} \\
+\frac{P_aC_a}{PC}\frac{\epsilon_p\theta_{pa}}{(1-\beta\theta_{pa})(1-\theta_{pa})}\pi_{a,t}^2 + \frac{P_nC_n}{PC}\frac{\epsilon_p\theta_{pn}}{(1-\beta\theta_{pn})(1-\theta_{pn})}\pi_{n,t}^2 \\
+\epsilon_w\left(\frac{P_aC_a+P_nC_n}{PC} + N^{1+\varphi}\varphi\epsilon_w\right)\frac{\theta_w}{(1-\beta\theta_w)(1-\theta_w)}\pi_{w,t}^2
\end{array} \right\}.
\end{aligned}
$$

Noting that $N^{1+\varphi} = \frac{WN}{PC} = \frac{WN_a+WN_n}{PC} = \frac{P_aY_a+P_nY_n}{PC} = \frac{P_aC_a+P_nC_n}{PC}$ we obtain

$$
\begin{aligned}
&\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \int_0^1 (U_t - U) dj \\
&= -\frac{1}{2}\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \begin{array}{c}
\left(\beta_a^{-1}\frac{P_a}{P}\chi_a^2 + \frac{P_a}{P}\chi_a\gamma_a\varphi\right)\tilde{y}_{a,t}^2 + \left(\frac{P_n}{P}\beta_n + \frac{P_n}{P}\beta_n\varphi\gamma_n\right)\tilde{y}_{n,t}^2 \\
-2\left(\frac{P_a}{P}\chi_a\frac{P_n}{P}\beta_n - \frac{P_a}{P}\chi_a\varphi\gamma_n\right)\hat{y}_{a,t}\hat{y}_{n,t} \\
+\frac{P_aC_a}{PC}\frac{\epsilon_p\theta_{pa}}{(1-\beta\theta_{pa})(1-\theta_{pa})}\pi_{a,t}^2 + \frac{P_nC_n}{PC}\frac{\epsilon_p\theta_{pn}}{(1-\beta\theta_{pn})(1-\theta_{pn})}\pi_{n,t}^2 \\
+\frac{P_aC_a+P_nC_n}{PC}\frac{\epsilon_w(1+\varphi\epsilon_w)\theta_w}{(1-\beta\theta_w)(1-\theta_w)}\pi_{w,t}^2
\end{array} \right\}.
\end{aligned}
$$

Finally, we divide both sides by $U_YY = U_cY = C^{-1}(\frac{P_a}{P}C_a + \frac{P_n}{P}C_n)$, and obtain welfare loss as percentage of steady state expenditure

$$
\begin{aligned}
\mathbb{W}_0 =& \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\int_0^1 (U_t - U) dj}{U_cY} \\
=& -\frac{1}{2}\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \begin{array}{c}
\Xi\frac{P_a}{P}\chi_a\left[\beta_a^{-1}\chi_a + \gamma_a\varphi\right]\tilde{y}_{a,t}^2 + \Xi\frac{P_n}{P}\beta_n\left(1+\varphi\gamma_n\right)\tilde{y}_{n,t}^2 \\
-2\Xi\left(\frac{P_a}{P}\chi_a\frac{P_n}{P}\beta_n - \frac{P_a}{P}\chi_a\varphi\gamma_n\right)\hat{y}_{a,t}\hat{y}_{n,t} \\
+\frac{P_aC_a}{P_aC_a+P_nC_n}\frac{\epsilon_p\theta_{pa}}{(1-\beta\theta_{pa})(1-\theta_{pa})}\pi_{a,t}^2 \\
+\frac{P_nC_n}{P_aC_a+P_nC_n}\frac{\epsilon_p\theta_{pn}}{(1-\beta\theta_{pn})(1-\theta_{pn})}\pi_{n,t}^2 \\
+\frac{\epsilon_w(1+\varphi\epsilon_w)\theta_w}{(1-\beta\theta_w)(1-\theta_w)}\pi_{w,t}^2
\end{array} \right\},
\end{aligned}
$$

where $\Xi \equiv \frac{PC}{P_aC_a+P_nC_n}$.

Appendix B. Figures and tables

Figure 2.1: Shock to agriculture in developing country

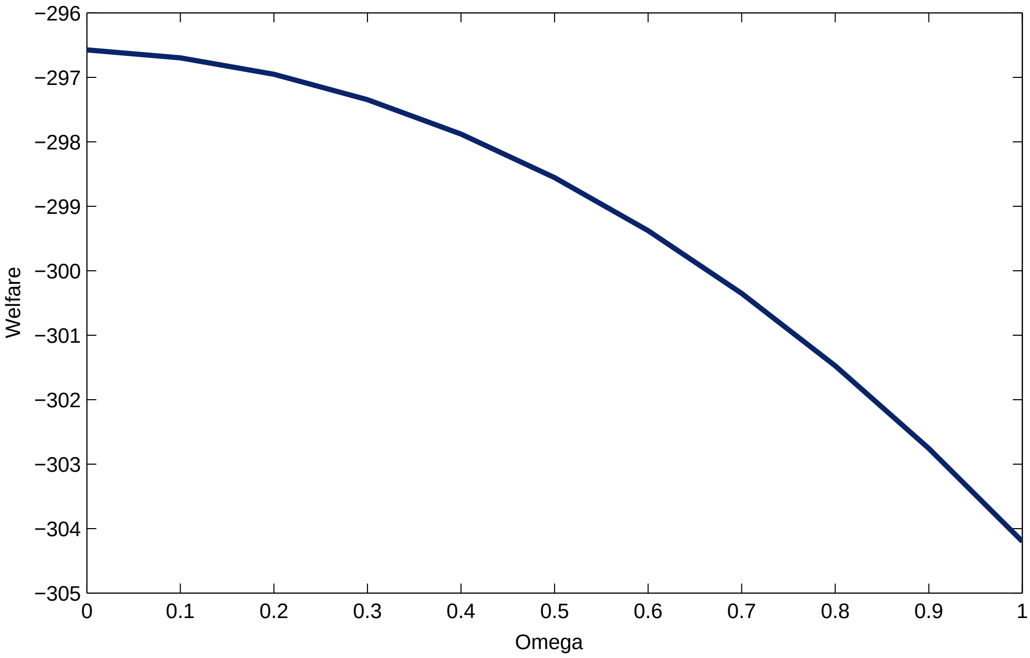


Figure 2.2: Shock to non-agriculture in developing country

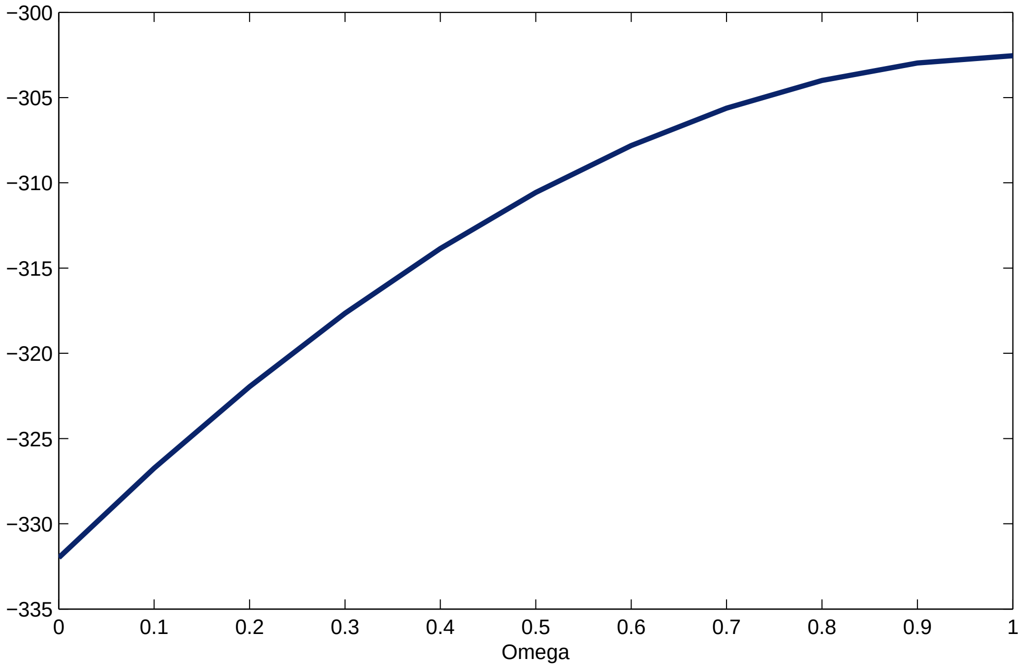


Figure 2.3: Both shocks in developing country

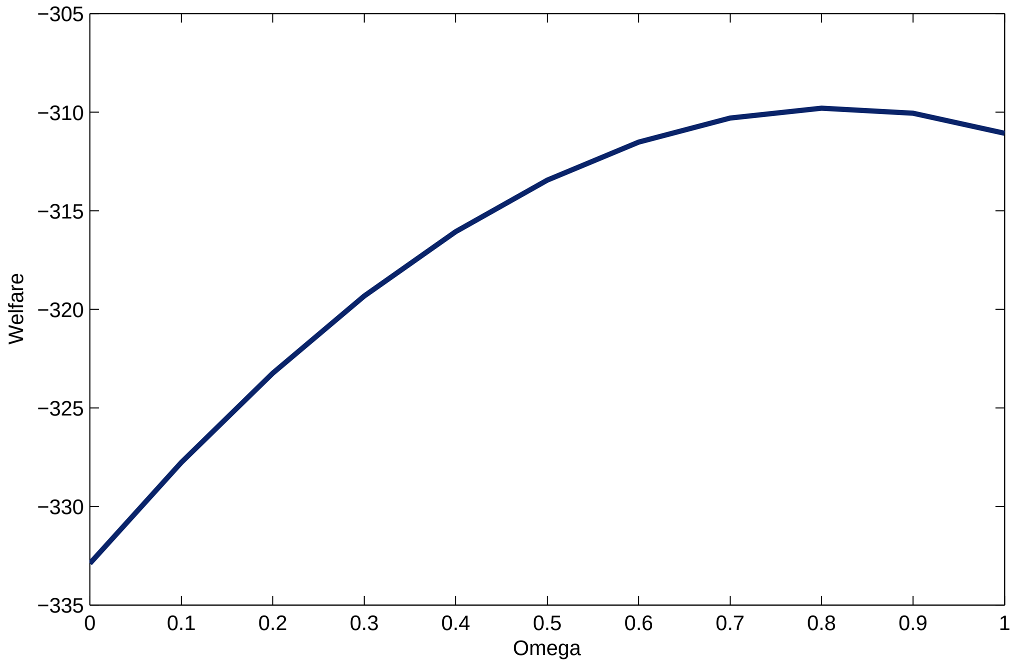
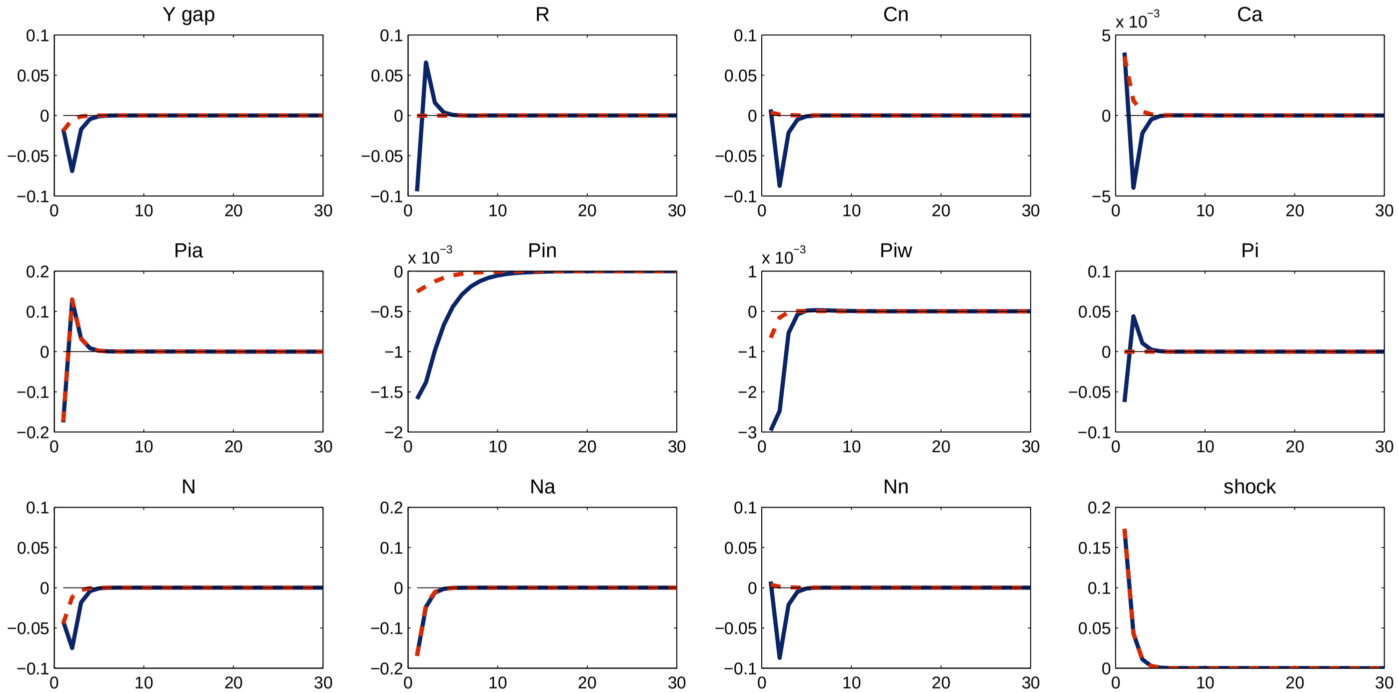
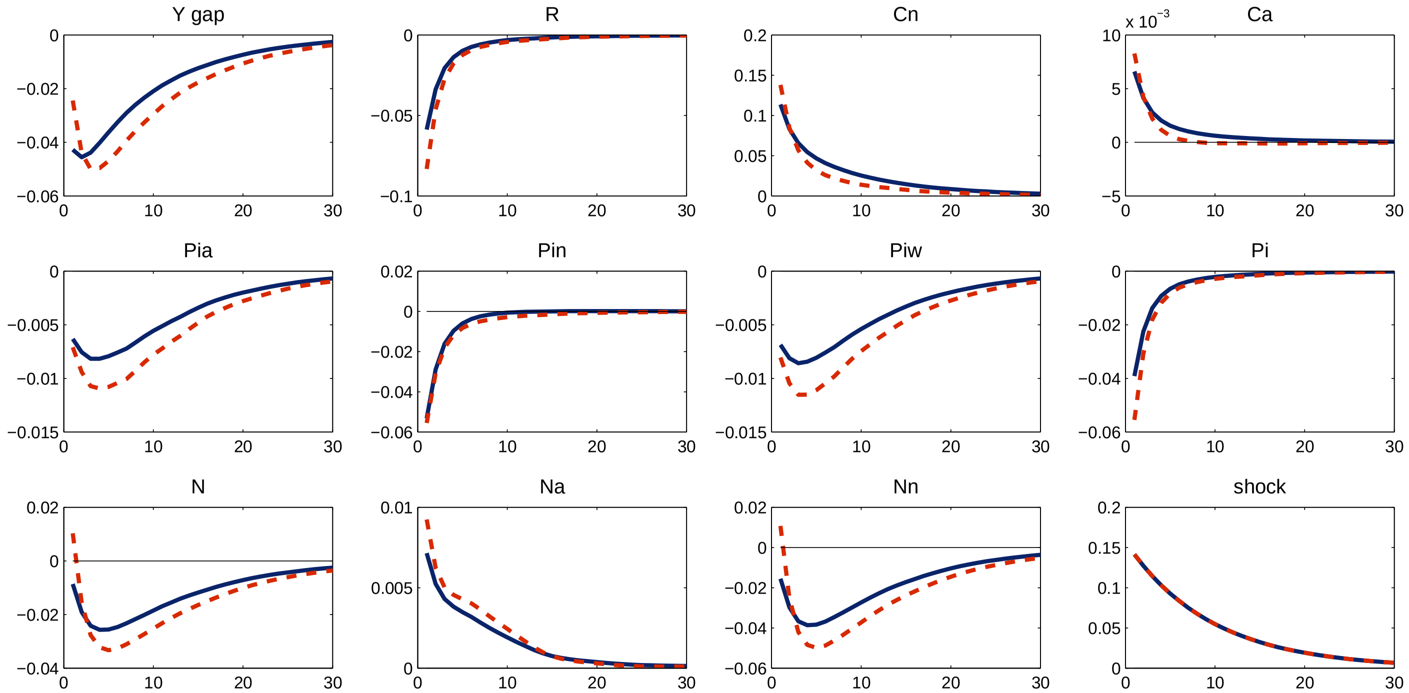


Figure 2.4: IRF of shock in agriculture in developing country



The continuous line shows impulse responses when the central bank targets headline inflation, $\Omega = 0.35$, while the dashed line shows the impulse response when the central bank targets core inflation, $\Omega = 0$. *Ygap* is output gap, *R* is the nominal interest rate, *Cn* is consumption in non-agriculture, *Ca* is consumption in agriculture, *Pia* is agricultural inflation, *Pin* is non-agricultural inflation, *Piw* is wage inflation, *Pi* is headline inflation when $\Omega = 0.35$ and core inflation when $\Omega = 0$, *N* is total employment, *Na* is agricultural employment, *Nn* is non-agricultural employment and *shock* is the agricultural productivity shock.

Figure 2.5: IRF of shock in non-agriculture in developing country



The continuous line shows impulse responses when the central bank targets headline inflation, $\Omega = 0.35$, while the dashed line shows the impulse response when the central bank targets core inflation, $\Omega = 0$. *Ygap* is output gap, *R* is the nominal interest rate, *Cn* is consumption in non-agriculture, *Ca* is consumption in agriculture, *Pia* is agricultural inflation, *Pin* is non-agricultural inflation, *Piw* is wage inflation, *Pi* is headline inflation when $\Omega = 0.35$ and core inflation when $\Omega = 0$, *N* is total employment, *Na* is agricultural employment, *Nn* is non-agricultural employment and *shock* is the non-agricultural productivity shock.

Figure 2.6: Shock to agriculture in rich country

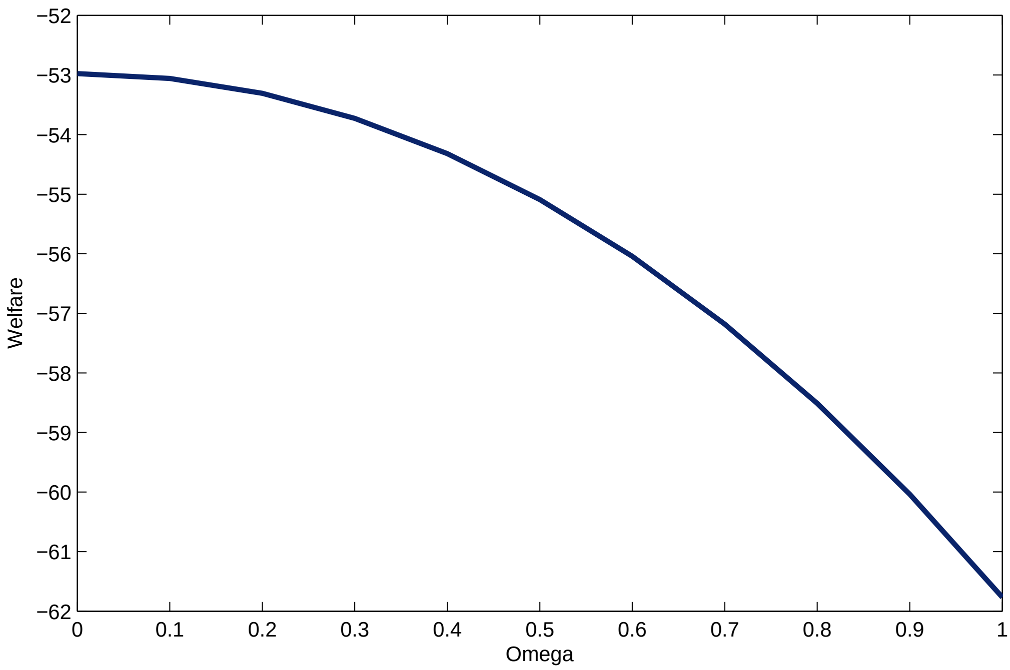


Figure 2.7: Shock to non-agriculture in rich country

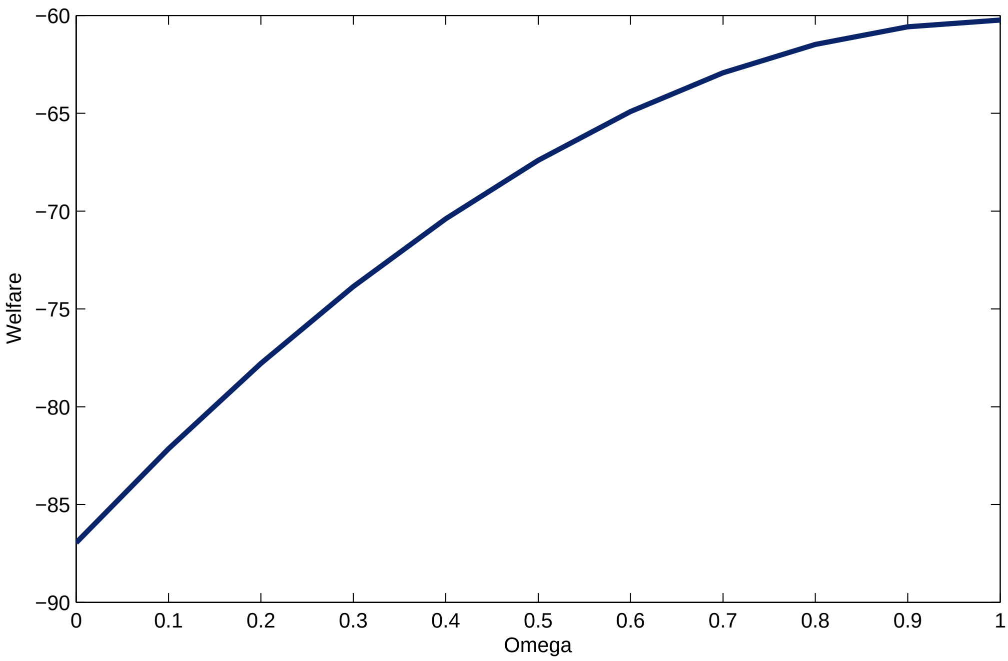


Figure 2.8: Both shocks in rich country

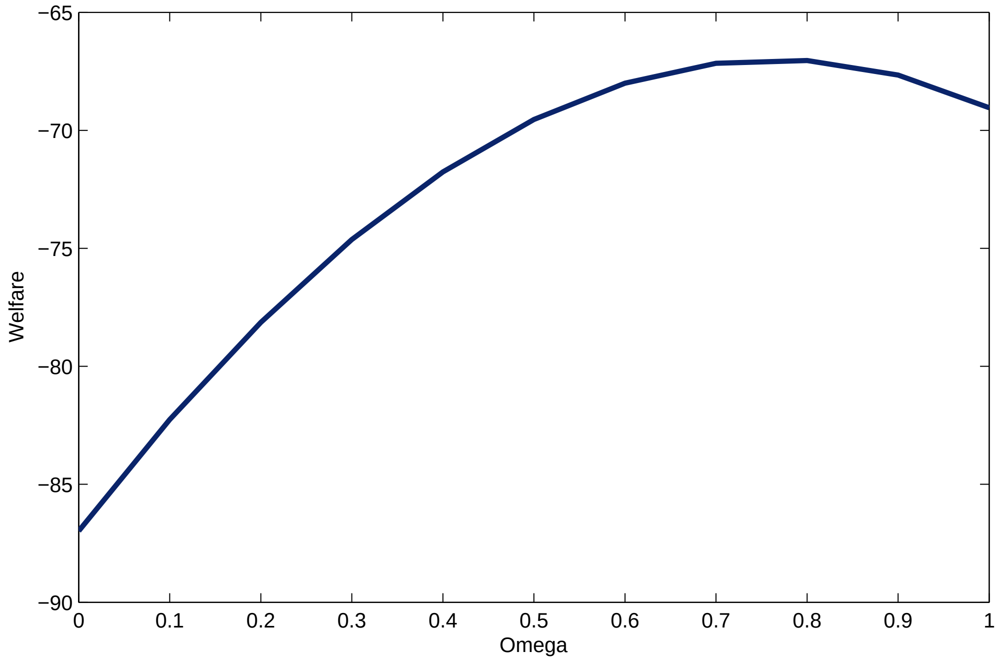
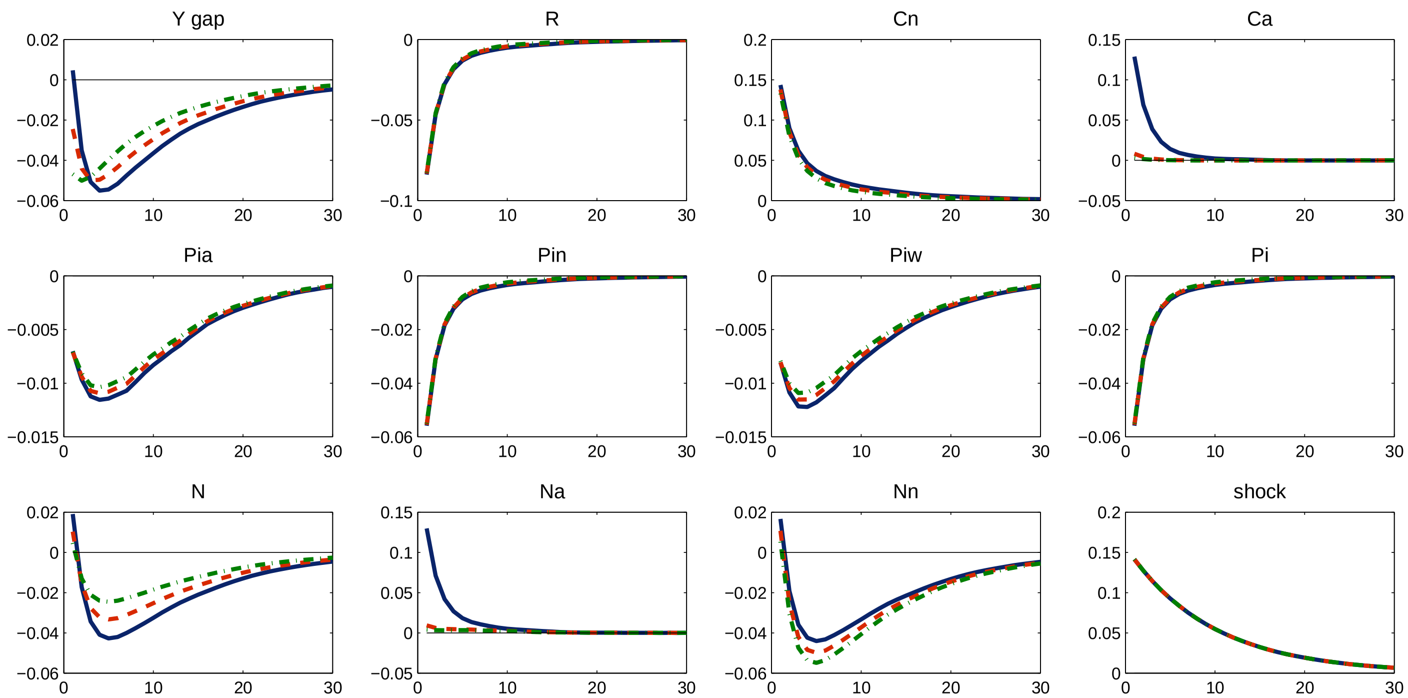
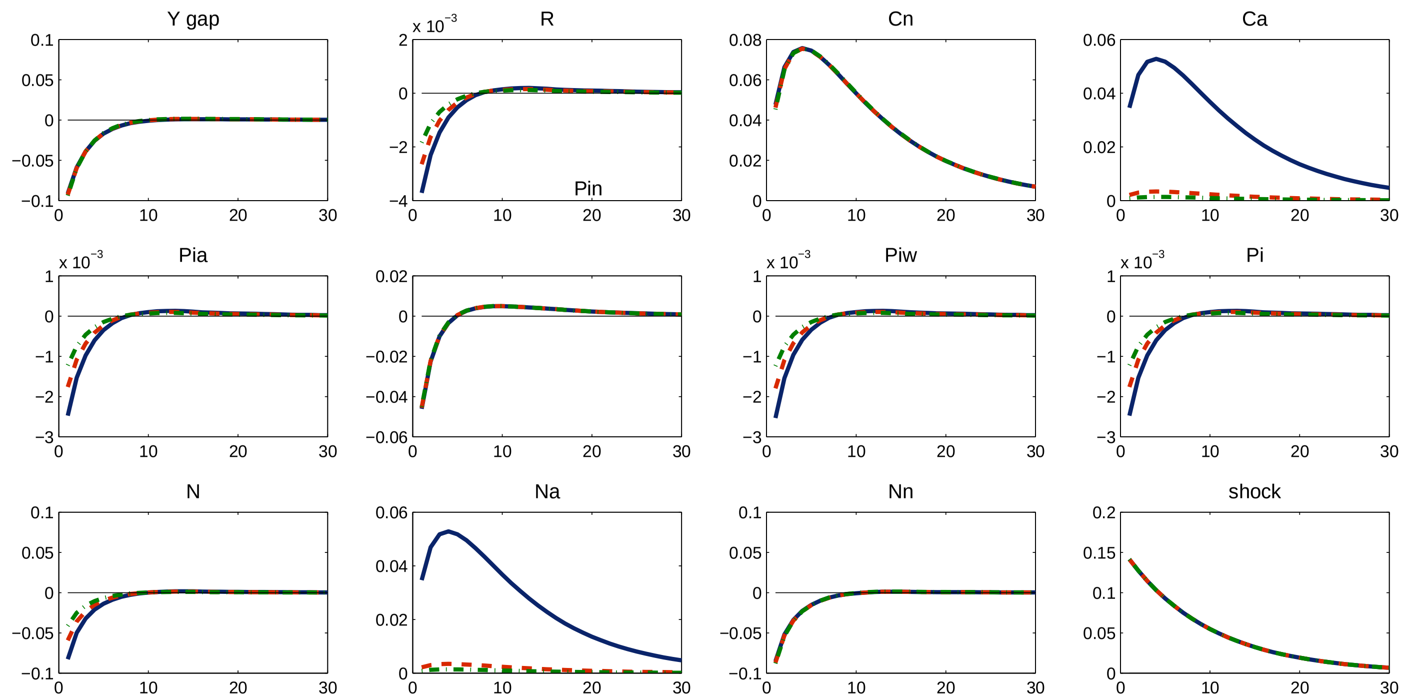


Figure 2.9: Shock in non-agriculture: rich vs developing ($\Omega = 0$)



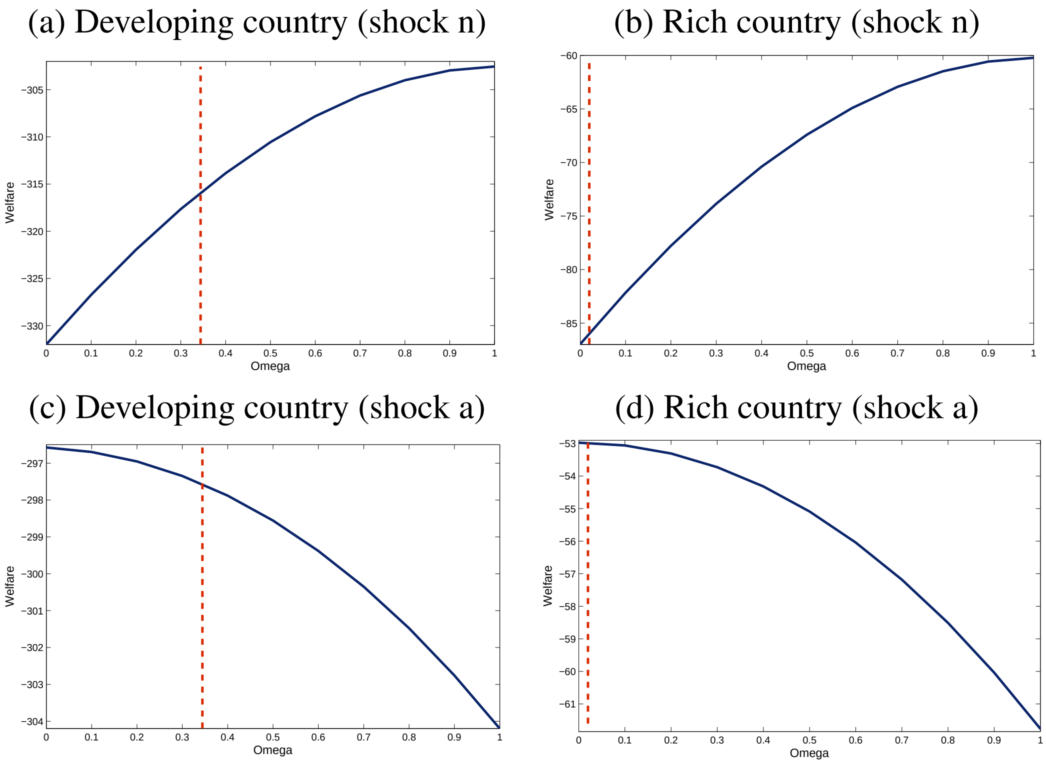
The figure shows impulse responses when the central bank targets core inflation, $\Omega = 0$. The continuous line shows impulse responses of a rich country with agricultural employment share of 2%, while the dashed line and the dashed and dotted line show impulse responses in developing countries with agricultural employment share of 30% and 50%, respectively. *Ygap* is output gap, *R* is the nominal interest rate, *Cn* and *Ca* are consumption in non-agriculture and agriculture, *Pia*, *Pin*, *Piw* and *Pi* are agricultural, non-agricultural, wage and core inflation, *N*, *Na* and *Nn* are total, agricultural and non-agricultural employment, and *shock* is the non-agricultural productivity shock.

Figure 2.10: Shock in non-agriculture: rich vs developing ($\Omega = 1$)



The figure shows impulse responses when the central bank assigns full weight to agricultural inflation, $\Omega = 1$. The continuous line shows impulse responses of a rich country with agricultural employment share of 2%, while the dashed line and the dashed and dotted line show impulse responses in developing countries with agricultural employment share of 30% and 50%, respectively. *Ygap* is output gap, *R* is the nominal interest rate, *Cn* and *Ca* are consumption in non-agriculture and agriculture, *Pia*, *Pin*, *Piw* and *Pi* are agricultural, non-agricultural, wage and core inflation, *N*, *Na* and *Nn* are total, agricultural and non-agricultural employment, and *shock* is the non-agricultural productivity shock.

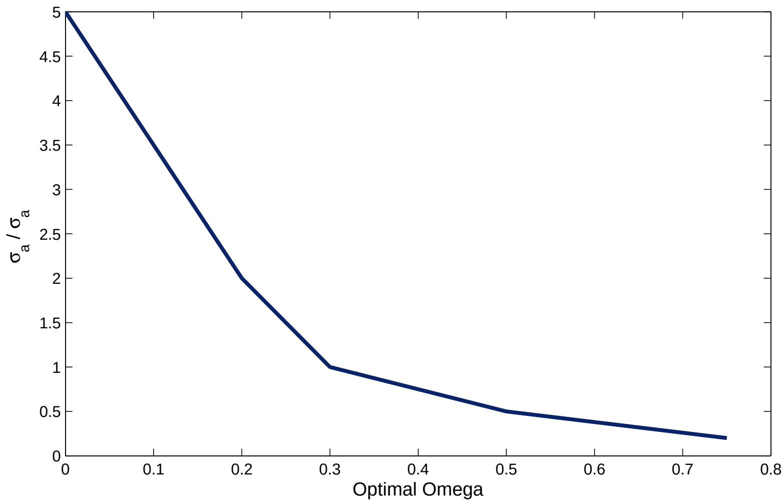
Figure 2.11



In this figure we compare welfare loss in rich and developing countries, given the measure of inflation, Ω. The vertical dashed line indicates headline inflation targeting, $\Omega = P_a C_a / PY$.

Figure 2.12

(a) Optimal Ω for different σ_a/σ_n



(b) Optimal Ω for different ρ_a/ρ_n

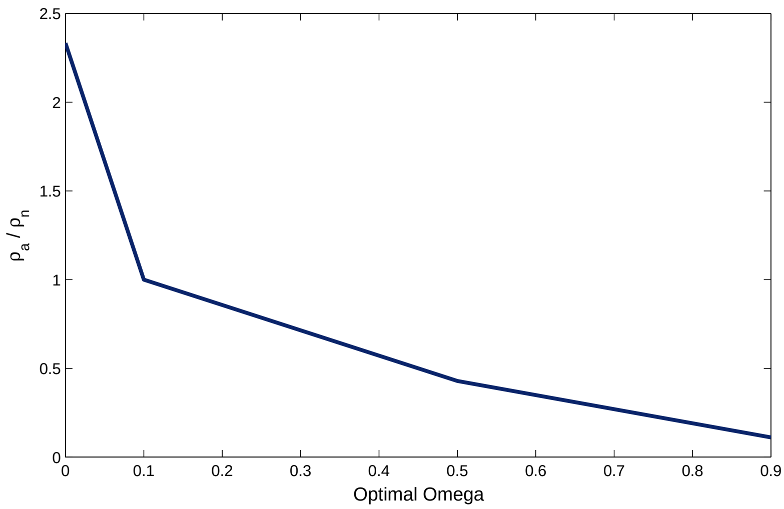


Table 2.1: Parameter values

Parameter	Description	Value
ω_a	Weight of agricultural goods in utility in rich countries	0.02
γ	Elasticity of substitution between agric. and non-agric. goods	0.3
$\tilde{C}_a$	Employment in agriculture in developing country (30%)	0.02808
A_n	Income of developing country $(15\%$ of the U.S.)	0.1284
A_a	Relative agricultural price in developing country $(1.5$ of U.S.)	$0.66 * A_n$
σ	Intertemporal elasticity of substitution	1
φ	Inverse of the Frisch elasticity of labor supply	1
β	Discount factor	0.99
ε_p	Elasticity of substitution of different goods varieties	6
ε_w	Elasticity of substitution of different labor varieties	6
θ_a	Probability of not reseting prices next period in sector a	0
θ_n	Probability of not reseting prices next period in sector n	$2/3$
θ_w	Probability of not reseting wages next period	$3/4$
ϕ_π	Weight assigned to price inflation in Taylor rule	1.5
ρ_a	Autocorrelation of productivity shock in a	0.25
ρ_n	Autocorrelation of productivity shock in n	0.9
σ_{va}	Standard deviation of shock in a	0.03
σ_{vn}	Standard deviation of shock in n	0.02

Table 2.2: Sources of welfare loss

Welfare Loss	Developing country		Rich country	
	$\Omega = 0$	$\Omega = 1$	$\Omega = 0$	$\Omega = 1$
$\tilde{y}_a^2$	0.0215	0.000	0.0272	0.0001
$\tilde{y}_n^2$	1.6828	1.0881	2.1282	1.5994
π_a^2	0.0001	0.0000	0.0000	0.0000
π_n^2	6.3878	3.4677	8.7592	4.6681
π_w^2	36.8258	0.2030	40.8572	0.3540
Total	44.9181	4.7589	51.7719	6.6215

3 Agricultural composition, structural change and labor productivity

3.1 Introduction[1]

A recent strand of the growth literature argues that a substantial part of cross-country income differences can be explained by differences in agricultural labor productivity between developing and developed countries.[2] 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. Since agricultural employment shares are high in developing countries, this literature concludes that cross-country income differences are, in part, the result of low labor productivity in this sector.

To account for differences in labor productivity between agriculture and non-agriculture in developing countries, the literature has focused on misallocations introduced by institutions (Chen (2016), 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)), selection (Lagakos and Waugh (2013)), differences in technology (Chen (2017), Gollin *et al.* (2007), Yang and Zhu (2013)), uninsurable risk and incomplete capital markets (Donovan (2016)), and differences in vintage capital (Caunedo and Keller (2016)).

[1] This chapter was written in collaboration with Xavier Raurich.

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

The aforementioned literature considers an aggregate agricultural sector producing a single commodity. It disregards the fact that agriculture products are diverse, that they can be produced with different technologies and that consumption of these products can change as the economy develops. The purpose of this paper is to study the process of structural change within agriculture, and how changes in the composition of this sector contribute to explain observed differences in agricultural labor productivity and income levels across countries.

We use crop level data, available at the Food and Agriculture Organization (FAO), to distinguish between two different agricultural sectors: a capital intensive and a land intensive. Since the database does not provide capital usage at crop level, we cannot identify directly which crops are produced with the capital intensive technology. Therefore, we follow an indirect approach. We obtain the ratio between the yield of a crop in U.S. and in country that has converge in income to U.S. levels. We compute this ratio during the period 1961-2014, for every crop available in the dataset. As a comparison country, we choose Spain, as this country has experienced convergence in both income and capital per worker with respect to U.S. levels.[3]

If the ratio of yields between countries has increased during the period 1961-2014, we consider the crop as capital intensive, if the ratio has not increased we regard the crop as land intensive. Note that this identification criteria implies that only capital intensive crops benefited from aggregate capital accumulation. In Table 3.1, we summarize the resulting classification of crops. According to our criteria most cereals are produced with the capital intensive technology, whereas vegetables and fruits are typically produced with the land intensive technology.

Using this classification, and the FAO dataset, we can compute production, prices and arable land for each agricultural sector. Figure 3.1, indicates that the relative price between land and capital intensive sectors increases, whereas the relative production between these two sectors declines. This evidence suggests imperfect substitution in consumption between agricultural goods.

As a framework of analysis, we use an overlapping generations (OLG)

[3]Per capita GDP in Spain was 40% of that in U.S. in 1961, and it has increased to 60% in 2014. Capital to GDP in Spain was 80% of that in the U.S. in 1961, and it has increased to levels above the ones currently observed in U.S.

model where a continuum of individuals is born in each period. These individuals have heterogeneous abilities in farming. As in Lucas (1978), young individuals with low abilities choose to be workers, whereas individuals with high ability 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 consume agricultural and non-agricultural products, subject to a minimum consumption requirement in agriculture. The agricultural good is a constant elasticity of substitution (CES) aggregate of capital and land intensive crops. Consistent with the data shown in Figure 3.1, we assume that the elasticity of substitution between capital and land intensive crops is larger than one.

Economic growth involves two different types of structural change. First, there is a decrease in the number of farmers in the agricultural sector, due to declining minimum consumption requirements in agriculture resulting from higher income. The remaining farmers have larger abilities and, therefore, larger farms. This is consistent with evidence provided by Adamopoulos and Restuccia (2014) who report that the average farm size in low income countries is 50 times smaller than farm sizes in high income countries. This process of structural change implies that agricultural productivity increases with economic development. The mechanism relating agricultural productivity and selection is examined in Lagakos and Waugh (2013).

Second, as capital becomes more abundant, the relative price of land to capital intensive crops increases, consistent with the evolution of prices in Figure 3.1. Given imperfect substitution between these goods, the relative production of land to capital intensive crops declines. As a consequence, agriculture becomes more capital intensive and labor in this sector more productive. In sum, in this chapter we propose increasing capital intensity in agriculture as the driving mechanism behind observed differences in agricultural productivity between developed and developing countries. The increase in capital intensity in agriculture relative to non-agriculture, along the process of economic development, is consistent with evidence provided by Chen (2016) and Alvarez-Cuadrado *et al.* (2013). In particular, Chen (2016) indicates that the capital-output ratio in agriculture is 3.2 times larger in developed countries than in developing countries, and only 2.1 times larger in non-agriculture.

This paper is closely related to Alvarez-Cuadrado *et al.* (2013), Chen (2017) and Gollin *et al.* (2007). In these papers, economic growth is associated to a more capital intensive agricultural sector. In Alvarez-Cuadrado *et al.* (2013) this process is the consequence of a CES production function in the agricultural sector, with substitutability between capital and labor. On the other hand, Chen (2017) and Gollin *et al.* (2007) introduce a process of technological change in agriculture, from land to capital intensive technology. In contrast to these authors, in this chapter the increase in capital intensity is the result of imperfect substitution between crops. We argue that the elasticity of substitution can differ across countries, depending on cultural factors or even level of development.

We simulate the model and show that the transitional dynamics it generates is consistent with the following facts associated to economic development: (i) a reduction in the employment share in agriculture, (ii) an increase in the average farm size, (iii) an increase in the capital-output ratio in agriculture relative to non-agriculture, and (iv) an increase in the productivity of agriculture relative to non-agriculture. In the numerical exercises we emphasize the importance of the elasticity of substitution. We find that low elasticity of substitution limits the process of structural change within agriculture and, as a consequence, the increase of labor productivity in this sector.

Finally, we study the effects of two different types of market inefficiencies. First, we assume an extreme labor mobility barrier that fixes the share of non-agricultural workers and of land and capital intensive farmers, as the economy develops. We use this extreme misallocation to show that, absent structural change, the model is unable to account for rising agricultural productivity. Second, we assume larger borrowing costs in agriculture than in non-agriculture. We show that this capital inefficiency, specific to agriculture, reduces labor productivity mainly at the start of the transition, when capital is scarce.

3.2 Model

3.2.1 Individuals

The economy is populated by a continuum of individuals of mass one. Individuals live for two periods. When young, they work and save. When old they consume the accumulated savings. Individuals are different regarding their abilities to be farmers. We denote the ability as a farmer of an individual by $a^i \in [a_{\min}, a_{\max}]$. These abilities follow a truncated Pareto distribution with density function $f\left(a^i\right) = \lambda a_{\min}^{\lambda}\left(a^i\right)^{-(1+\lambda)} / \left(1 - a_{\min}^{\lambda} a_{\max}^{-\lambda}\right)$ and cumulative function $F\left(a^i\right) = (1 - a_{\min}^{\lambda}(a^i)^{-\lambda})/(1 - a_{\min}^{\lambda} a_{\max}^{-\lambda})$. In addition, we assume that all individuals have the same ability as workers in non-agriculture.

An individual i derives utility from consumption in the second period of his life according to

$$U_t^i = \omega \ln\left(c_{a,t+1}^i - \bar{c}\right) + (1-\omega)\ln c_{n,t+1}^i, \tag{3.1}$$

where $c_{a,t+1}^i$ is the consumption of agricultural goods, $c_{n,t+1}^i$ is the consumption of non-agricultural goods, $\bar{c}$ 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 an aggregate of goods produced with either a capital or a land intensive technology. We assume that these goods are imperfect substitutes. Therefore, $c_{a,t+1}^i$ is defined as

$$c_a^i = \left[\mu\left(c_L^i\right)^{\frac{\varepsilon-1}{\varepsilon}} + (1-\mu)\left(c_K^i\right)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{3.2}$$

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

Let total consumption expenditure be

$$E_{t+1}^i \equiv P_{n,t+1}c_{n,t+1}^i + P_{L,t+1}c_{L,t+1}^i + P_{K,t+1}c_{K,t+1}^i, \tag{3.3}$$

where $P_{L,t+1}$ is the price of the land intensive goods, $P_{K,t+1}$ is the price of the capital intensive goods and $P_{n,t+1} = 1$ for all t, as the output of the non-agricultural sector is assumed to be the numeraire. The individuals' consumption demands are obtained from maximizing utility subject to (3.3) as[4]

$$c^i_{L,t+1} = \omega\mu^\varepsilon \left(\frac{P_{L,t+1}}{P_{a,t+1}}\right)^{1-\varepsilon} \frac{E^i_{t+1}}{P_{L,t+1}} + (1-\omega)\,\mu^\varepsilon \left(\frac{P_{L,t+1}}{P_{a,t+1}}\right)^{-\varepsilon} \bar{c}, \tag{3.4}$$

$$c^i_{K,t+1} = \omega(1-\mu)^\varepsilon \left(\frac{P_{K,t+1}}{P_{a,t+1}}\right)^{1-\varepsilon} \frac{E^i_{t+1}}{P_{K,t+1}} + (1-\omega)\,(1-\mu)^\varepsilon \left(\frac{P_{K,t+1}}{P_{a,t+1}}\right)^{-\varepsilon} \bar{c}, \tag{3.5}$$

$$c^i_{n,t+1} = (1-\omega)\,E^i_{t+1} - (1-\omega)\,P_{a,t+1}\bar{c}, \tag{3.6}$$

where

$$P_{a,t+1} \equiv \left(\mu^\varepsilon P^{1-\varepsilon}_{L,t+1} + (1-\mu)^\varepsilon P^{1-\varepsilon}_{K,t+1}\right)^{\frac{1}{1-\varepsilon}}. \tag{3.7}$$

3.2.2 Technology

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

$$Y_{n,t} = A_n K^{\alpha_n}_{n,t} N^{1-\alpha_n}_{n,t}, \tag{3.8}$$

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

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

and

$$R_t = \alpha_n A_n K^{\alpha_n - 1}_{n,t} N^{1-\alpha_n}_{n,t}. \tag{3.9}$$

As capital completely depreciates, the rental price of capital satisfies $R_t = 1 + r_t$, where r_t is the interest rate. Note that the output of this sector is the numeraire of the economy. Finally, it will be useful for our analysis to obtain

[4]See appendix A.1 for details on the derivation of consumption demands

the following relationship

$$w_t = \alpha_n^{\frac{\alpha_n}{1-\alpha_n}} (1-\alpha_n) A_n^{\frac{1}{1-\alpha_n}} R_t^{\frac{\alpha_n}{\alpha_n - 1}}. \tag{3.10}$$

An individual working in agriculture has ownership over the farm. Farmers can produce using either a land or a capital intensive technology. Land intensive farms produce according to the following technology

$$y_{L,t}^i = A_L a^i \left(L_{L,t}^i\right)^{\beta_L}, \tag{3.11}$$

where $y_{L,t}^i$ is the output produced by a farmer with ability a^i in the land intensive sector, A_L is the productivity parameter, $L_{L,t}^i$ is the amount of land that a farmer with ability a^i buys and $\beta_L \in (0,1)$ measures the decreasing returns to land. In order to buy land, the young farmer borrows from the credit market. When old, the farmer pays the credit and the interest rate, $\widetilde{r}_t$. We assume that financial markets are not perfect in agriculture and, hence, there is a financial inefficiency that we denote by $\tau > 1$. It follows that $\widetilde{r}_t = \tau r_t$ and

$$\widetilde{R}_t \equiv 1 + \widetilde{r}_t = \tau R_t + (1-\tau). \tag{3.12}$$

Note that $\widetilde{R}_t > R_t$ implies that the cost of the credit is larger than the rental price of capital. Finally, when old, farmers sell the land. Hence, the profit of a land intensive farm that produces in period t and sells the land in period $t+1$ is

$$\pi_{L,t}^i = P_{L,t} y_{L,t}^i - \left(\widetilde{R}_t P_t - P_{t+1}\right) L_{L,t}^i,$$

where $P_{L,t}$ is the price of the land intensive agricultural product and P_t is the price of land. Farmers choose land to maximize $\pi_{L,t}^i$. It follows that the demand of land is

$$L_{L,t}^i = \left(\frac{\beta_L P_{L,t} A_L a^i}{x_t}\right)^{\frac{1}{1-\beta_L}}, \tag{3.13}$$

where

$$x_t = \widetilde{R}_t P_t - P_{t+1} \tag{3.14}$$

is the rental cost of one unit of land. Note that the size of a land intensive farm, measured by $L_{L,t}^i$, increases with farmer's ability, but decreases with the cost of land. Note also that this cost increases with the financial inefficiency, reducing farm sizes. Finally, we replace (3.13) in the profit function to obtain

$$\pi^i_{L,t}\left(a^i\right) = (1-\beta_L)\left[\left(\frac{\beta_L}{x_t}\right)^{\beta_L} P_{L,t}A_L a^i\right]^{\frac{1}{1-\beta_L}}. \tag{3.15}$$

Capital intensive farms produce using capital and land according to the following production function

$$y^i_{K,t} = A_K a^i \left(L^i_{K,t}\right)^{\beta_K}\left(K^i_{K,t}\right)^{\alpha_K}, \tag{3.16}$$

where $y^i_{K,t}$ is the agricultural output produced by a farmer with ability a^i in the capital intensive sector, A_K is productivity parameter, $L^i_{K,t}$ and $K^i_{K,t}$ are, respectively, the amount of land and capital used in production and $\beta_K \in (0,1)$ and $\alpha_K \in (0,1)$ measure, respectively, the land and capital to output elasticities. We assume that $\beta_K + \alpha_K < 1$ and, hence, the production function exhibits decreasing returns to scale.

Farmers in the capital intensive sector borrow from the markets to buy capital and land. These farmers are subject the financial inefficiency, implying that when old they must pay the cost $\widetilde{R}_t$ for the credit obtained when young. At this point, it is important to clarify that the financial inefficiency is specific of the agricultural sector, which can be explained by higher monitoring costs. Finally, when old, farmers sell the land but not the capital, as it completely depreciates after one period. It follows that the profit of a capital intensive farm is

$$\pi^i_{K,t} = P_{K,t}y^i_{K,t} - x_t L^i_{K,t} - \widetilde{R}_t K^i_{K,t},$$

where $P_{K,t}$ is the price of capital intensive agricultural output.

Farmers choose land and capital to maximize $\pi^i_{K,t}$. From the first order conditions, we obtain that the demands of capital and land are, respectively,

$$K^i_{K,t} = \left[\left(\frac{\alpha_K}{\widetilde{R}_t}\right)^{1-\beta_K}\left(\frac{\beta_K}{x_t}\right)^{\beta_K} P_{K,t}A_K a^i\right]^{\frac{1}{1-\beta_K-\alpha_K}}, \tag{3.17}$$

$$L^i_{K,t} = \left[\left(\frac{\alpha_K}{\widetilde{R}_t}\right)^{\alpha_K}\left(\frac{\beta_K}{x_t}\right)^{1-\alpha_K} P_{K,t}A_K a^i\right]^{\frac{1}{1-\beta_K-\alpha_K}}. \tag{3.18}$$

Optimal profits are given by

$$\pi_{K,t}^{i}\left(a^{i}\right)=\left(1-\beta_K-\alpha_K\right)\left[\left(\frac{\alpha_K}{\widetilde{R}_t}\right)^{\alpha_K}\left(\frac{\beta_K}{x_t}\right)^{\beta_K}P_{K,t}A_K a^{i}\right]^{\frac{1}{1-\beta_K-\alpha_K}}. \tag{3.19}$$

Note that the optimal size of the capital intensive farm, given by (3.18), increases with ability and decreases with both the cost of land and the financial inefficiency.

3.2.3 Individuals' decisions

Young individuals decide the sector where they work. Obviously, this decision depends on their abilities. To understand this decision, we derive the ability of the marginal individual, indifferent between working in non-agriculture and in the land intensive agricultural sector. Let us denote by $\underline{a}_t$ the ability of this marginal individual. Then, individuals with an ability lower than $\underline{a}_t$ will prefer to work in non-agriculture. This ability is obtained from solving the following equation: $\pi_{L,t}^{i}\left(\underline{a}_t\right)=w_t$. Using (3.10) and (3.13), we find that

$$\underline{a}_t=\left(\frac{\alpha_n^{\frac{\alpha_n}{1-\alpha_n}}\left(1-\alpha_n\right)A_n^{\frac{1}{1-\alpha_n}}R_t^{\frac{\alpha_n}{\alpha_n-1}}}{\left(1-\beta_L\right)P_{L,t}A_L}\right)^{1-\beta_L}\left(\frac{x_t}{\beta_L P_{L,t}A_L}\right)^{\beta_L}. \tag{3.20}$$

We denote by $\overline{a}_t$ the ability of the marginal individual that is indifferent between being a farmer in the land or the capital intensive sector. This ability is obtained from solving the following equation: $\pi_{L,t}^{i}\left(\overline{a}_t\right)=\pi_{K,t}^{i}\left(\overline{a}_t\right)$. From using (3.13), (3.17) and (3.18), we obtain

$$\begin{aligned}\overline{a}_t \;=\; & \left[\left(\frac{\alpha_K}{\beta_K}\right)^{\alpha_K}\left(\frac{(1-\beta_K-\alpha_K)P_{K,t}A_K}{(1-\beta_L)P_{L,t}A_L}\right)^{1-\beta_K-\alpha_K}\left(\frac{\beta_K P_{K,t}A_K}{\widetilde{R}_t}\right)^{\alpha_K+\beta_K}\right.\\ & \left.\left(\frac{\widetilde{R}_t}{x_t}\right)^{\beta_K}\left(\frac{x_t}{\beta_L P_{L,t}A_L}\right)^{\frac{\beta_L(1-\beta_K-\alpha_K)}{1-\beta_L}}\right]^{\frac{1-\beta_L}{\beta_L-\beta_K-\alpha_K}}.\end{aligned} \tag{3.21}$$

If $\beta_L<\beta_K+\alpha_K$, individuals with ability above $\overline{a}_t$ will be farmers of a capital intensive farm, whereas individuals with ability below $\overline{a}_t$ will be either farmers in land intensive agriculture or workers in the non-agricultural sector.[5] More precisely, under appropriate parameter constraints, we have that $\overline{a}_t > \underline{a}_t$ and, hence, individuals with $a^i \in [a_{\min}, \underline{a}_t]$ will be workers in the non-agricultural sector, individuals with $a^i \in [\underline{a}_t, \overline{a}_t]$ will be farmers in the land intensive sector and individuals with $a^i \in [\overline{a}_t, a_{\max}]$ will be farmers in the capital intensive sector. From now one, we assume that $\beta_L < \beta_K + \alpha_K$ and $\overline{a}_t > \underline{a}_t$ so that the aforementioned characterization of individual occupational decisions holds.

The condition $\beta_L \leq \beta_K/(1-\alpha_K)$ has two important implications. First, the marginal individual $\overline{a}_t$ decreases with the rental cost of land. This implies that the fraction of capital intensive farms increases with the cost of land. Second, it implies that the size of the farm of the marginal individual is larger if he decides to be a farmer in the capital intensive sector, that is $L^i_{L,t}(\overline{a}_t) \leq L^i_{K,t}(\overline{a}_t)$. Hence, when farmers shift to the capital intensive sector the size of the average farm increases. In fact, when the inequality $\beta_L < \beta_K/(1-\alpha_K)$ is strict, the distribution of land sizes will not be continuous as there is a gap between $L^i_{L,t}(\overline{a}_t)$ and $L^i_{K,t}(\overline{a}_t)$. To avoid this undesired feature, we assume that $\beta_L = \beta_K/(1-\alpha_K)$.[6]

The previous assumption implies that the value of production of the marginal individual satisfies $P_L y^i_{L,t}(\overline{a}_t) < P_K y^i_{K,t}(\overline{a}_t)$. In turn, this implies an output gain when an extra farmer shifts to the capital intensive sector. This production increase is generated by a productivity gain. In order to see this, we use (3.11), (3.13), (3.16), and (3.18) to show that

$$\frac{P_L y^i_{L,t}}{L^i_{L,t}} = \frac{x_t}{\beta_L},$$

and

$$\frac{P_K y^i_{K,t}}{L^i_{K,t}} = \frac{x_t}{\beta_K}.$$

As $\beta_L > \beta_K$, the production per unit of land is clearly larger in the capital intensive farms.

[5] This result follows from using (3.15) and (3.19) and taking into account that $\pi^i_{L,t}(\overline{a}_t) = \pi^i_{K,t}(\overline{a}_t)$.

[6] To show this result, it is enough to realize that $L^i_{T,t}/\pi^i_{T,t} = \beta_T/[x_t(1-\beta_T)]$ and that $L^i_{M,t}/\pi^i_{M,t} = \beta_M/[x_t(1-\beta_M-\alpha_M)]$. As $\pi^i_{T,t}(\overline{a}) = \pi^i_{M,t}(\overline{a})$ then $L^i_{T,t}(\overline{a}) \leq L^i_{M,t}(\overline{a})$ if and only if $\beta_T \leq \beta_M/(1-\alpha_M)$.

3.3 Equilibrium

Individuals consume when old the income they generate when young. The consumption expenditure of an old individual that was a non-agricultural worker in period t is $E_{t+1}^{n,i} = R_{t+1}w_t$. The expenditure of an old individual that was a land intensive farmer is $E_{t+1}^{L,i} = R_{t+1}\pi_{L,t}^{i}\left(a^i\right)$. Similarly, the expenditure of an old individual that was a capital intensive farmer is $E_{t+1}^{K,i} = R_{t+1}\pi_{K,t}^{i}\left(a^i\right)$. Hence, aggregate consumption expenditure is given by[7]

$$E_{t+1} = \int_{a_{\min}}^{\underline{a}_t} E_{t+1}^{n,i} f\left(a^i\right) di + \int_{\underline{a}_t}^{\bar{a}_t} E_{t+1}^{L,i} f\left(a^i\right) di + \int_{\bar{a}t}^{a_{\max}} E_{t+1}^{K,i} f\left(a^i\right) di. \quad (3.22)$$

Using (3.4), (3.5) and (3.6), we obtain aggregate consumption of land and capital intensive agricultural products, and aggregate consumption of non-agricultural products that, respectively, are given by

$$C_{L,t+1} = \omega\mu^{\varepsilon}\left(\frac{P_{L,t+1}}{P_{a,t+1}}\right)^{1-\varepsilon}\frac{E_{t+1}}{P_{L,t+1}} + (1-\omega)\,\mu^{\varepsilon}\left(\frac{P_{a,t+1}}{P_{L,t+1}}\right)^{\varepsilon}\bar{c}, \quad (3.23)$$

$$C_{K,t+1} = \omega(1-\mu)^{\varepsilon}\left(\frac{P_{K,t+1}}{P_{a,t+1}}\right)^{1-\varepsilon}\frac{E_{t+1}}{P_{K,t+1}} + (1-\omega)\,(1-\mu)^{\varepsilon}\left(\frac{P_{a,t+1}}{P_{K,t+1}}\right)^{\varepsilon}\bar{c}, \quad (3.24)$$

$$C_{n,t+1} = (1-\omega)\,E_{t+1} - (1-\omega)\,P_{a,t+1}\bar{c}. \quad (3.25)$$

The aggregate demands of land and capital in each sector and the aggregate productions are used to characterize the equilibrium of this economy. In order to obtain the aggregate demand of land in the land and capital intensive agricultural sectors, we use (3.13) and (3.18) to obtain

$$L_{L,t} = \int_{\underline{a}}^{\bar{a}} L_{L,t}^{i} f\left(a^i\right) di = \left(\frac{\beta_L P_{L,t} A_L}{x_t}\right)^{\frac{1}{1-\beta_L}} \Delta_{L,t}, \quad (3.26)$$

[7] Appendix A.2 provides an analytical expression of aggregate expenditure.

and

$$\begin{aligned} L_{K,t} &= \int_{\bar{a}}^{a_{\max}} L_{K,t}^{i} f\left(a^{i}\right) di \\ &= \left[\left(\frac{\alpha_K}{\widetilde{R}_t}\right)^{\alpha_K} \left(\frac{\beta_K}{x_t}\right)^{1-\alpha_K} P_{K,t} A_K\right]^{\frac{1}{1-\beta_K-\alpha_K}} \Delta_{K,t}, \end{aligned} \quad (3.27)$$

where $\Delta_{L,t}$ and $\Delta_{K,t}$ are defined in Appendix A.2.

To obtain the aggregate demand of capital in capital intensive agriculture and in non-agriculture, we use (3.17) and (3.9) to obtain

$$\begin{aligned} K_{K,t} &= \int_{\bar{a}}^{a_{\max}} K_{K,t}^{i} f\left(a^{i}\right) di \\ &= \left[\left(\frac{\alpha_K}{\widetilde{R}_t}\right)^{1-\beta_K} \left(\frac{\beta_K}{x_t}\right)^{\beta_K} P_{K,t} A_K\right]^{\frac{1}{1-\beta_K-\alpha_K}} \Delta_{K,t}, \end{aligned} \quad (3.28)$$

and

$$K_{n,t} = \left(\frac{\alpha_n A_n}{R_t}\right)^{\frac{1}{1-\alpha n}} N_{n,t}, \quad (3.29)$$

where the amount of workers in the non-agricultural sector is $N_n = F(\underline{a}) = \left(1 - a_{\min}^{\lambda} \underline{a}^{-\lambda}\right) / \left(1 - a_{\min}^{\lambda} a_{\max}^{-\lambda}\right)$. We define by K_t the total stock of capital that satisfies

$$K_t = K_{n,t} + K_{K,t}. \quad (3.30)$$

Finally, we use (3.11) and (3.16) to obtain the aggregate production of land and capital intensive agricultural goods

$$Y_{L,t} = \int_{\underline{a}}^{\bar{a}} y_{L,t}^{i} f\left(a^{i}\right) di = A_L \left(\frac{\beta_L P_{L,t} A_L}{x_t}\right)^{\frac{\beta_L}{1-\beta_L}} \Delta_{L,t}, \quad (3.31)$$

and

$$\begin{aligned} Y_{K,t} &= \int_{\bar{a}}^{a_{\max}} y_{K,t}^{i} f\left(a^{i}\right) di \\ &= A_K \left[\left(\frac{\alpha_K}{\widetilde{R}_t}\right)^{\alpha_K} \left(\frac{\beta_K}{x_t}\right)^{\beta_K} \left(P_{K,t} A_K\right)^{\alpha_K+\beta_K}\right]^{\frac{1}{1-\beta_K-\alpha_K}} \Delta_{K,t}. \end{aligned} \quad (3.32)$$

Before defining the equilibrium, we must take into account that the financial inefficiency introduces a cost, interpreted as a monitoring cost, that enters into the resource constraint of the non-agricultural sector. This financial cost is given by $\Omega_t = (\tau - 1) r_t \left(P_t L + K_{K,t}\right)$.

Given K_0, an equilibrium of this economy is a path of ability thresholds $\{\underline{a}_t, \overline{a}_t\}_{t=0}^{\infty}$ that satisfies (3.20) and (3.21), a path of aggregate demands of land $\left\{L_{L,t}, L_{K,t}\right\}_{t=0}^{\infty}$ that satisfies (3.27) and (3.26), a path of aggregate demands of capital $\left\{K_{n,t}, K_{K,t}\right\}_{t=0}^{\infty}$ that satisfies (3.28) and (3.29), a path of aggregate consumption demands $\left\{C_{n,t}, C_{K,t}, C_{L,t}\right\}_{t=0}^{\infty}$ that satisfies (3.23), (3.24) and (3.25), a path of sectoral outputs $\left\{Y_{n,t}, Y_{K,t}, Y_{L,t}\right\}_{t=0}^{\infty}$ that satisfies (3.8), (3.31) and (3.32), a path of aggregate consumption expenditure and capital $\{E_t, K_t\}_{t=0}^{\infty}$ that satisfies (3.22) and (3.30), a path of prices $\{P_{a,t}, \widetilde{R}_t, R_t, P_{L,t}, P_{K,t}, x_t\}_{t=0}^{\infty}$ that satisfies (3.7) and (3.12), and market clearing conditions for land intensive agricultural goods, $C_{L,t} = Y_{L,t}$, for capital intensive agricultural goods, $C_{K,t} = Y_{K,t}$, for non-agricultural products, $Y_{n,t} = C_{n,t} + K_{t+1} + \Omega_t$, and for land holdings $L = L_{L,t} + L_{K,t}$, where L is the fixed amount of total agricultural land.

3.4 Numerical simulations

3.4.1 Calibration

As a first step, we use data from FAO for the U.S. economy and compute the value of production, the share of land and the price index (base year 2014) for both agricultural sectors. Figure 3.1 summarizes the data. As observed in the figure, the relative price of land to capital intensive agricultural goods increases, while the ratio between the value of production in these sectors declines. This implies that the agricultural goods are substitutes in consumption. The elasticity of substitution consistent with this data is such that $\varepsilon = 10$. This elasticity also accounts for the reduction in the share of land allocated in land intensive agriculture (see Panel (e) of Figure 3.1).

The value of production in 2014 and the price indexes are also used to calibrate the parameters of the production functions. Valentinyi and Herrendorf (2008) provide capital and land income shares in agriculture and in non-agriculture for the U.S. economy. We use these shares and the relation $\beta_L = \beta_K / (1 - \alpha_K)$ to obtain the values for α_n, α_K, β_K and β_L. In particular, the capital and land income shares in agriculture satisfy the following equations

$$\beta_L \frac{P_L Y_L}{P_K Y_K + P_L Y_L} + \beta_K \frac{P_K Y_K}{P_K Y_K + P_L Y_L} = 0.18,$$
$$\alpha_K \frac{P_K Y_K}{P_K Y_K + P_L Y_L} = 0.36,$$

where $P_L Y_L / (P_K Y_K + P_L Y_L)$ is the fraction of agricultural value added generated in the land intensive sector in 2014, the land income share in agriculture equals 0.18 and the capital income share in agriculture equals 0.36.

On the other hand, the productivity parameters of the different sectors are set as follows: A_n is normalize to one, A_L is set to match the value of the ratio between the two price indexes in 2014, which is equal to one, and A_K is set to a value such that the labor productivity in agriculture equals the labor productivity in non-agriculture in steady state.[8]

Regarding the preference parameters, ω is set so that the long-run share of employment in the agricultural sector equals 1%, μ is set to match the fraction of agricultural value added generated in the capital intensive sector in 2014, and $\bar{c}$ is set to match the fraction of employment in the agricultural sector in 2014.

The parameters characterizing the distribution of abilities are set to match the distribution of farms sizes reported by Adamopoulos and Restuccia (2014). In particular, we normalize $a_{\min}$ to one and we set $a_{\max}$ to match the range of farm sizes in the U.S. Finally, λ is set so that 38% of farms are small (less than 50 hectares).

Finally, we set $\tau = 1$ which implies no financial inefficiency. The parameter values and the targets of calibration are summarized in Table 3.2.

[8] A note of caution is in order. We consider agricultural productivity in units of land intensive goods, whereas non-agricultural productivity is measured in units of non-agricultural goods. We set A_K such that the ratio of these two measures equals one in the last period of the simulation. We use this measure of relative productivity as a normalization, to highlight the growth of relative productivities, which is the target of our analysis. Note that we are not interested in explaining the level of the relative productivity. If this was the case, we should consider nominal relative productivity. As in Chen (2016) and others, the model can only explain the level of nominal relative productivity by introducing an inefficiency parameter in the labor market.

3.4.2 Structural change and labor productivity

Figure 3.2 shows the transitional dynamics of the benchmark economy from an initially low capital stock level.[9] Therefore, capital accumulation drives economic growth in this economy. Panel (a) shows the process of structural change out of agriculture. This is driven by an income effect, resulting from declining minimum consumption requirements. Taking into account that a period is about 20 years, the first three periods of the simulation match the structural transformation exhibited by the U.S. economy during the period 1961-2014.

The reduction of the agricultural employment share implies an increase in average farm sizes. This is shown in Panel (b), where the average farm size is decomposed between the two agricultural sectors. The panel shows large differences in average farm size between agricultural sectors, and that the fast increase in the average farm size is mostly explained by the shift of farmers to the capital intensive sector. This process of structural change within agriculture is shown in Panels (c), (d) and (f). Panel (c) displays the land share used in land intensive agriculture. From the comparison to Figure 3.1, we can conclude that the model can explain most of the reduction. Panel (d) shows the process of structural change within agriculture in terms of labor, while Panel (f) in terms of production. Comparing the simulated series to the data, we find that the model matches data on production.

The process of structural change between the two agricultural sectors is due to the increase in the relative price illustrated in Panel (e). The simulation is consistent with the long-run evolution of the prices in the data. The rise in the relative price is explained in the model by capital accumulation along the transition, that benefits the capital intensive agricultural sector.

The aforementioned process of structural change explains the increase in capital intensity in agriculture relative to non-agriculture. This is shown in Panel (g). The relative capital intensity between the capital intensive agricultural sector and non-agriculture (continuous line) is constant and slightly above one. The relative capital intensity between total agriculture and non-agriculture (dashed line) exhibits an increasing pattern. To account for this

[9] We assume that the initial capital stock is 20% of its steady state level. This implies that if capital grows at a 2% annual growth rate, the economy will be close to its steady state after 4 periods (80 years).

pattern, we introduce the following decomposition

$$\frac{K_{K,t}/(P_{K,t}Y_{K,t}+P_{L,t}Y_{L,t})}{K_{n,t}/Y_{n,t}} = \frac{R_t}{\widetilde{R}_t}\left(\frac{P_{K,t}Y_{K,t}}{P_{K,t}Y_{K,t}+P_{L,t}Y_{L,t}}\right)\frac{\alpha_K}{\alpha_n}, \tag{3.33}$$

where we make use of equations (3.9), (3.28) and (3.32). Note that relative capital intensity depends on three components: the inefficiency in the capital market, the sectoral composition within the agricultural sector and the capital output elasticities. In the absence of inefficiencies, as it is assumed in the benchmark simulation, and without production in land intensive agriculture the capital intensity would be constant and equal to $\alpha_K/\alpha_n = 1.41$. Therefore, the increase in the capital intensity shown in Panel (g) is the result of a process of structural change within the agriculture, where the fraction of the value added generated by the capital intensive sector increases.

The last panel in Figure 3.2 shows the increase of labor productivity in agricultural sector relative to non-agriculture. This pattern is the consequence of two forces: the increase in the average farm size and the increase of the capital intensity in agriculture. This pattern implies that along the development process the labor productivity grows faster in agriculture.

In sum, the benchmark economy illustrated in Figure 3.2 is consistent with the following development facts: (i) a reduction in the employment share in agriculture, (ii) an increase in the average farm size, (iii) an increase in the capital intensity in agriculture relative to non-agriculture, and (iv) an increase in relative labor productivity in agriculture.

At this point, it is important to clarify that our contribution is to distinguish between the two agricultural sectors. If we had assumed a single agricultural sector, the model would not explain the increase in relative capital intensity and would imply a substantially smaller increase in farm sizes. As a consequence, the model would fail to generate a sufficient increase in agricultural labor productivity. In fact, it would decline in the absence of structural change within agriculture. To clarify this point, we illustrate in Panel (h) relative labor productivities in the land and in the capital intensive sectors. As observed in this panel labor productivity is higher in capital intensive agriculture. Therefore, the rising relative labor productivity shown in Panel (i) results from farmers moving to the more productive sector.

The aforementioned mechanism of structural change crucially depends on the elasticity of substitution between agricultural goods. Figure 3.3 shows the simulation of three economies that differ in the value of this elasticity. We illustrate the following cases: the benchmark economy, where goods are imperfect substitutes ($\varepsilon = 10$), an economy with strong substitution ($\varepsilon = 100$), and an economy where goods are complementary ($\varepsilon = 0.9$). As expected, Panel (e) shows that the relative price increases in the three economies. Panel (g) shows the evolution of the ratio between the value of production. This ratio increases when goods are complementaries and declines when they are substitutes. From the comparison to Figure 3.1, we find that the the elasticity of substitution consistent with the data is such that $\varepsilon = 10$.

The fraction of land and of farmers in the agricultural land intensive sector is larger when the elasticity of substitution is small (see Panels (c) and (d) of Figure 3.3). As the productivity of this sector is smaller, a low value of the elasticity of substitution implies that the total number of farmers is larger (Panel (a)) and the average farm size is smaller (Panel (b)). In other words, a low elasticity of substitution limits structural change within agriculture. In fact, Panel (c) shows that if goods are complementaries the fraction of land in the land intensive sector slightly increases. This explains why the relative capital intensity in agriculture is both smaller and constant through the transition, when the elasticity is low.

Finally, Panel (i) shows that relative labor productivity in agriculture is smaller and grows less when the elasticity of substitution is low. This results from smaller average farm sizes and lower relative capital intensity. We conclude that the value of the elasticity of substitution, by shaping the process of structural change within agriculture, is crucial to explain the increase in labor productivity in agriculture relative to non-agriculture.

Thus far, low agricultural labor productivity is a consequence of low capital stock in developing countries. This is in contrast to a large part of the literature, that argues in favor of a misallocation of resources. Following this literature, we introduce inefficiencies in the next section.

3.4.3 Misallocation

In this section, we consider the effects of two inefficiencies: an extreme labor mobility barrier and an imperfection in the capital market. The former implies fixed shares of individuals working in non-agriculture and in land intensive farms, as the economy develops. In other words, Na, N_K and N_L

remain constant. The dashed lines in Figure 3.4 display the transitional dynamics for this economy, while the continuous lines the simulation for the benchmark economy. This figure allows us to study how structural change affects labor productivity in agriculture.

Panel (i) shows that the ratio of labor productivity between agriculture and non-agriculture declines when barriers to labor mobility limit structural change. On the one hand, average farm size remains constant when N_a is fixed and, hence, it does not contribute to increase labor productivity (see Panel (b)). On the other hand, since the fraction of capital intensive farms is fixed, capital intensity in agriculture is near constant (flat dashed line in Panel (h)). Both effects limit the growth of labor productivity in agriculture. Finally, Panel (g) shows large differences in output across economies.

The second source of inefficiency introduced in this section are differences in the cost of borrowing between agriculture and non-agriculture. Banerjee (2001), Banerjee and Duflo (2005), Banerjee and Moll (2010) and Karlan (2013) provide evidence showing that borrowing interest rates are larger in developing countries, specially in agriculture. In Figure 3.5 we show how inefficiencies in capital markets in agriculture affect sectoral composition and labor productivity in this sector. The continuous lines in Figure 3.5 shows the simulation of an economy without financial inefficiencies, $\tau = 1$. The dashed lines show the simulation results for an economy with $\tau = 1.5$.

The inefficiency causes an initial large decline in total consumption expenditures (see Panel (f)). The income effect, resulting from non-homothetic preferences, increases the number of farmers in the economy with $\tau = 1.5$ and, hence, the average farm size is initially smaller. The inefficiency implies $R/\widetilde{R} < 1$ which, according to (3.33), reduces capital intensity in agriculture relative to non-agriculture, as shown in Panel (h).

As capital accumulates, the relative labor productivity in agriculture grows faster in the economy with $\tau = 1.5$. This is explained by the changes in both relative capital intensity and in average farm size. On one hand, as capital accumulates, the interest rates declines and the ratio $R/\widetilde{R}$ increases. The evolution of this ratio explains the fast increase of capital intensity in the economy with $\tau = 1.5$. On the other hand, the financial cost increases the demand of non-agricultural goods. As a consequence, the price of this sector increases leading low ability farmers to non-agriculture. This effect dominates the labor market decisions when the income effect is sufficiently small.

As economic development reduces the income effect, eventually the number of farmers becomes smaller in the economy with $\tau = 1.5$, which explains a larger average farm size. Clearly, both the evolution of farm size and of capital intensity explains why the relative labor productivity in the economy with $\tau = 1.5$ is larger later in the transition. Finally, Panels (f) and (g) show that, although output is larger in the economy with $\tau = 1.5$, total consumption expenditures are lower.

We emphasize that the increase in the relative labor productivity is larger when $\tau = 1.5$. Therefore, in line with previous findings in the literature, the misallocation contributes to explain differences in agricultural labor productivity between countries of different income levels. We conclude that the financial inefficiency and the process of structural change within agriculture provide complementary explanations for labor productivity differences in agriculture.

3.5 Concluding remarks

The literature reports that 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, explaining these large differences in agricultural productivity are central to understanding cross-country income differences. In this paper, we argue that structural change in the sectoral composition within agriculture can explain part of the low agricultural productivity observed in the developing world.

We consider two agricultural sectors that differ only in the degree of capital intensity in production. As capital becomes abundant, the price of the land intensive sector relative the capital intensive sector increases. This relative price change drives a process of structural change within agriculture and it depends on the elasticity of substitution between agricultural goods. We show that structural change, driven by economic growth, implies (i) a reduction in the number of farmers, mainly in the land intensive sector, (ii) an increase in the average farm size, and (iii) an increase in the capital intensity of the agricultural sector relative to non-agriculture. Higher average farm size and agricultural capital intensity lead to higher labor productivity in agriculture.

When the two agricultural goods are complementary in preferences, we find that labor productivity gains in agriculture are substantially lower. In this case, the sectoral composition within agriculture and the capital intensity remain constant, while the average farm size is small.

We conclude that the elasticity of substitution drives structural change within agriculture and is a key determinant of agricultural productivity. We acknowledge the need to estimate this parameter for a set of countries across different income levels. We are also aware of the need to perform further robustness checks on the classification of crops obtained from the comparison between crop yields in U.S. and Spain. Future work involves expanding the set of comparison countries.

Appendix A. Derivations

A1. Consumers' problem

In this appendix we derive the solution to the consumer problem, summarized in equations (3.4), (3.5) and (3.6). The consumer chooses c_L, c_K and c_n to maximize (3.1) subject to (3.2) and (3.3). We break the problem in two steps.

First, consumers choose c_L^i and c_K^i to maximize (3.2) 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

$$c_{L,t+1}^i = \mu^\varepsilon \left(\frac{P_{L,t+1}}{P_{a,t+1}}\right)^{1-\varepsilon} \frac{E_{a,t+1}}{P_{L,t+1}}, \tag{3.34}$$

$$c_{K,t+1}^i = (1-\mu)^\varepsilon \left(\frac{P_{K,t+1}}{P_{a,t+1}}\right)^{1-\varepsilon} \frac{E_{a,t+1}}{P_{K,t+1}}, \tag{3.35}$$

where

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

Note that this price satisfies

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

Second, consumers choose c_a^i and c_n^i by maximizing (3.1) subject to

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

Maximization implies equation (3.6) 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 (3.34) and (3.35), we can obtain equations (3.4) and (3.5).

A2. Aggregate consumption expenditures

Using (3.22), we obtain aggregate consumption expenditure as

$$E_t = R_t w_{t-1} \int_{a_{\min}}^{\underline{a}_{t-1}} f\left(a^i\right) di + R_t \int_{\underline{a}_{t-1}}^{\bar{a}_{t-1}} \pi^i_{L,t-1}\left(a^i\right) f\left(a^i\right) di +$$
$$R_t \int_{\bar{a}_{t-1}}^{a_{\max}} \pi^i_{K,t-1}\left(a^i\right) f\left(a^i\right) di. \tag{3.36}$$

We next use (3.10), (3.15) and (3.19), to obtain

$$E_t = R_t \alpha_n^{\frac{\alpha_n}{1-\alpha_n}} \left(1-\alpha_n\right) A_n^{\frac{1}{1-\alpha_n}} R_{t-1}^{\frac{\alpha_n}{\alpha_n - 1}} \frac{1-a_{\min}^{\lambda}\left(\underline{a}_t\right)^{-\lambda}}{\left(1-a_{\min}^{\lambda} a_{\max}^{-\lambda}\right)} +$$
$$R_t \left(1-\beta_L\right) \left[\left(\frac{\beta_L}{x_{t-1}}\right)^{\beta_L} P_{L,t-1} A_L\right]^{\frac{1}{1-\beta_L}} \Delta_{L,t-1} +$$
$$R_t \left(1-\beta_K-\alpha_K\right) \left[\left(\frac{\alpha_K}{\widetilde{R}_{t-1}}\right)^{\alpha_K} \left(\frac{\beta_K}{x_{t-1}}\right)^{\beta_K} P_{K,t-1} A_K\right]^{\frac{1}{1-\beta_K-\alpha_K}} \Delta_{K,t-1},$$

where

$$\Delta_{L,t} = \left(\frac{\lambda a_{\min}^{\lambda}}{1-a_{\min}^{\lambda} a_{\max}^{-\lambda}}\right) \left(\frac{\left(\bar{a}_t\right)^{\frac{1}{1-\beta_L}-\lambda} - \left(\underline{a}_t\right)^{\frac{1}{1-\beta_L}-\lambda}}{\frac{1}{1-\beta_L} - \lambda}\right),$$
$$\Delta_{K,t} = \frac{\lambda a_{\min}^{\lambda}}{1-a_{\min}^{\lambda} a_{\max}^{-\lambda}} \left(\frac{\left(a_{\max}\right)^{\frac{1}{1-\beta_K-\alpha_K}-\lambda} - \left(\bar{a}_t\right)^{\frac{1}{1-\beta_K-\alpha_K}-\lambda}}{\frac{1}{1-\beta_K-\alpha_K} - \lambda}\right).$$

Appendix B. Tables and figures

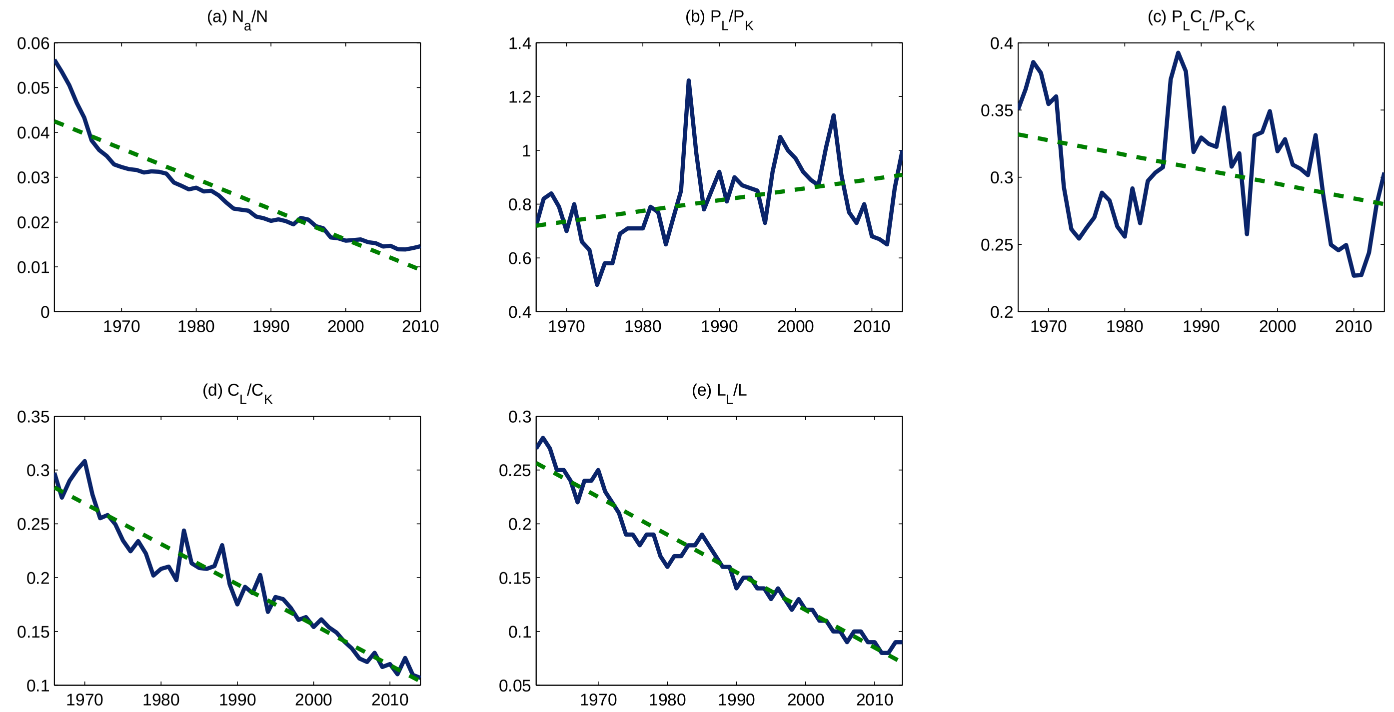
Table 3.1: Classification of crops

Land intensive crops:
Almonds (with shell), apricots, artichokes, asparagus, avocados, bananas, barley, cabbages (and other brassicas), cauliflowers and broccoli, cherries, chillies and peppers (green), dates, figs, garlic, groundnuts (with shell), lemons and limes, lentils, lettuce and chicory, fruit (fresh nes), melons (inc. cantaloupes), millet, oats, onions (dry), oranges, peaches and nectarines, pears, rice (paddy), sorghum, spinach, sunflower seed, sweet potatoes, strawberries, tangerines (incl. mandarins, clementines, satsumas), vegetables (fresh nes.), walnuts (with shell), and watermelons.
Capital intensive crops:
Beans (dry), beans (green), carrots and turnips, cucumbers and gherkins, eggplants (aubergines), grapefruit (inc. pomelos), grapes, hops, maize, plums and sloes, potatoes, rye, safflower seed, soybeans, sugar cane, tobacco (unmanufactured), tomatoes, wheat.

Table 3.2: Calibration

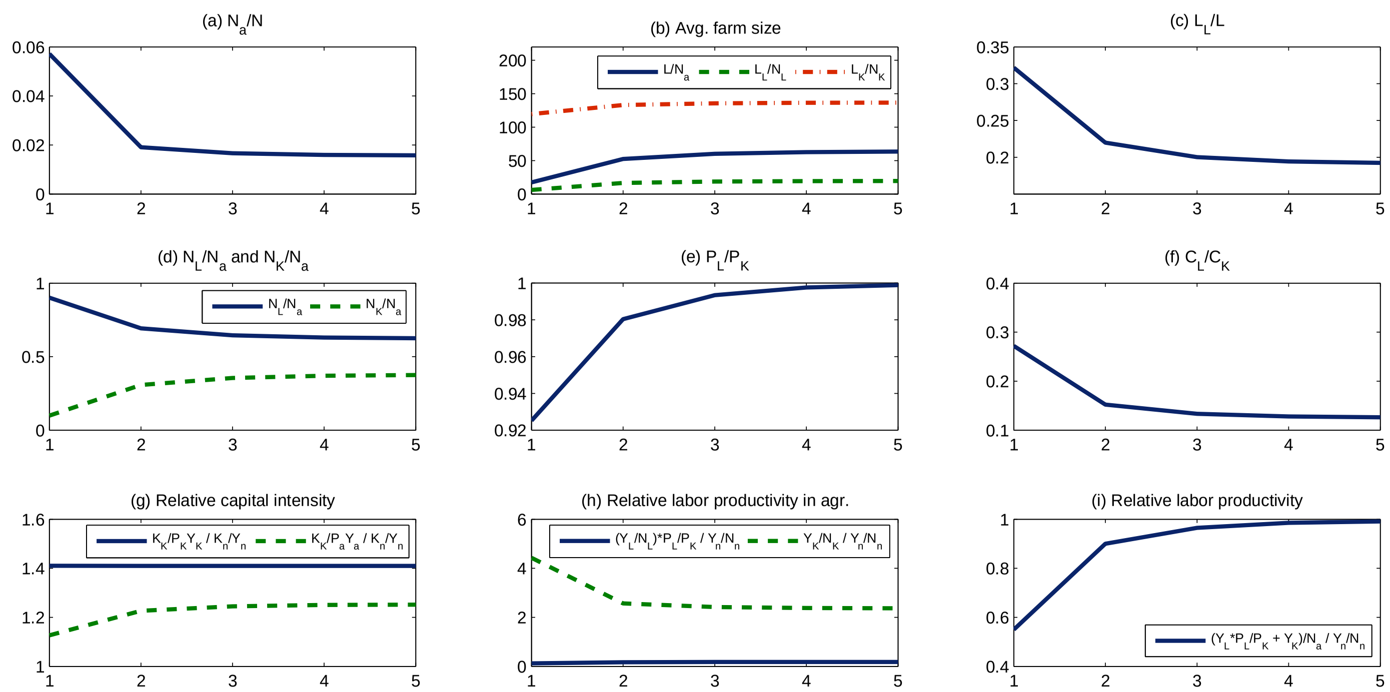
Parameter	Value	Target
ω	0.01	Long-run employment share in agriculture
$\bar{c}$	0.0044	Employment share in agriculture in U.S. in 2014 (1.5%)
μ	0.4482	$P_L Y_L/(P_L Y_L + P_K Y_K) = 0.23$ in U.S. in 2014
ϵ	10	Land share in land intensive agr. in U.S. in 1961 (28%)
A_n	1	Normalization
A_L	0.17	$P_L/P_K = 1$ in 2014
A_K	0.446	$(Y_L(P_L/P_K) + Y_K)/N_a/Y_n/N_n = 1$ in 2014
α_n	0.33	Valentinyi and Herrendorf (2008)
β_L	0.283	$\beta_L = \beta_K(1 - \alpha_K)$
β_K	0.15	$\beta_L(P_L Y_L)/(P_L Y_L + P_K Y_K) + \beta_K(P_K Y_K)/(P_L Y_L + P_K Y_K) = 0.18$
α_K	0.47	$\alpha_K(P_K Y_K)/(P_L Y_L + P_K Y_K) = 0.36$
λ	0.751	Distribution of farm size in U.S. in 2007 (38% of farms with less than 50 ha).
$a_{\min}$	0.001	Range of farm sizes between 1 and 2000 ha.
$a_{\max}$	1	Normalization
τ	1	Developed economy
L	1	Normalization

Figure 3.1: Data



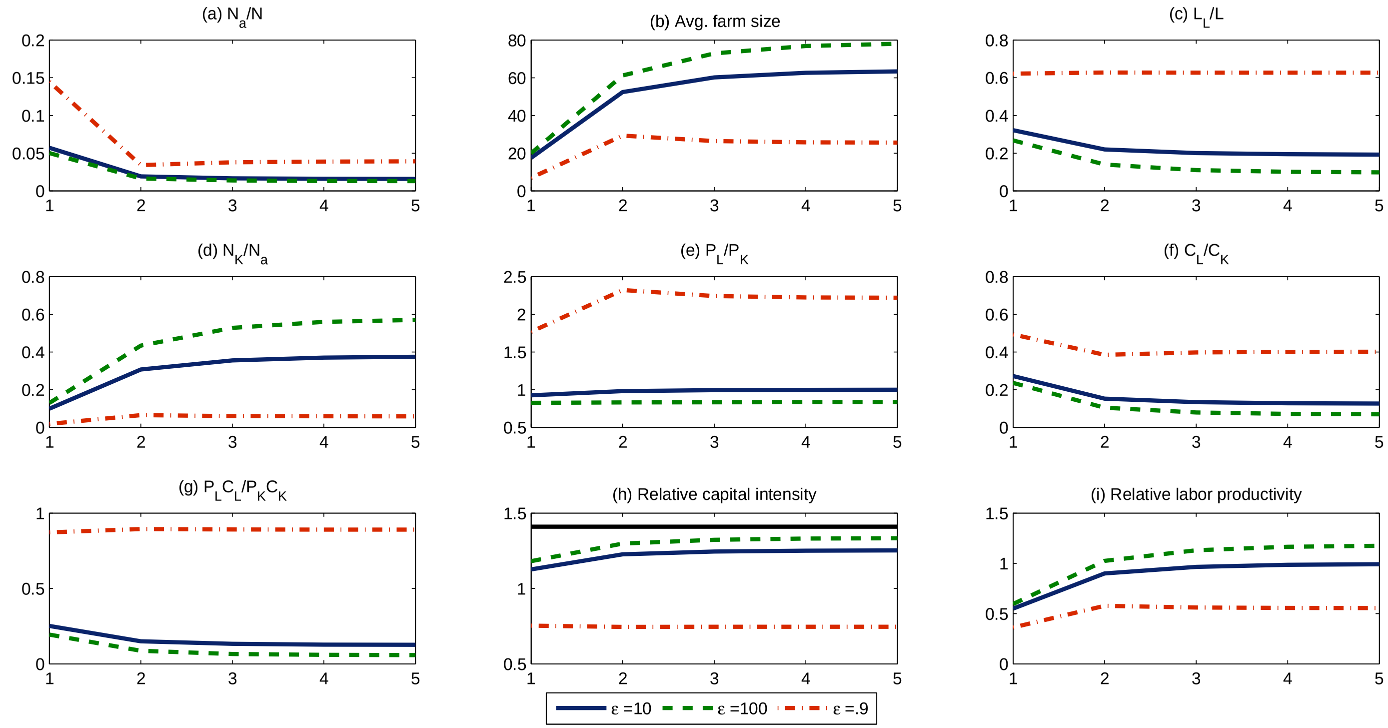
We use data available at FAO. The continuous line indicates observed data, the dashed line is a linear trend. The variables N_a/N, P_L/P_K, P_LC_L/P_KC_K, C_L/C_K and L_L/L indicate employment share in agriculture, relative price of land intensive to capital intensive agricultural goods, ratio of expenditure in land intensive agricultural goods to capital intensive agricultural goods, ratio of land intensive agricultural real output to capital intensive real output, and land share in land intensive crops, respectively.

Figure 3.2: Benchmark model



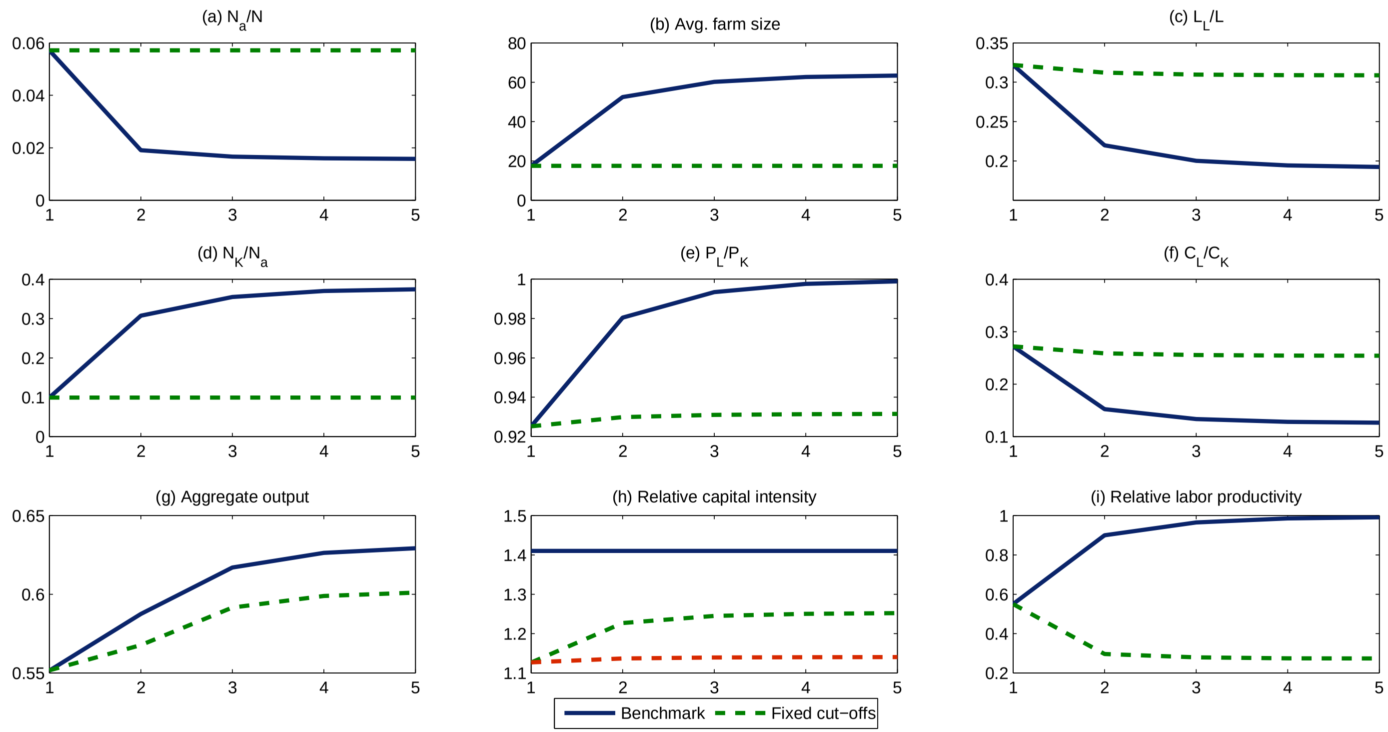
Panel (a) shows employment share in agriculture. Panel (b) average farm size (continuous line), avg. farm size in the land intensive sector (dashed line) and in the capital intensive sector (dashed and dotted line). Panle (c) land share in land intensive sector. Panel (d) shows agricultural employment in land intensive sector (continuous line) and in the capital intensive sector (dashed line). Panel (e) the relative price. Panel (f) relative real output. Panel (g) the relative capital intensity in capital intensive agriculture (continuous line) and in total agriculture (dashed line). Panel (h) relative real agricultural productivity in capital intensive agriculture (dashed line) and in land intensive agriculture (continuous line). Panel (i) the relative real labor productivity.

Figure 3.3: Different ε



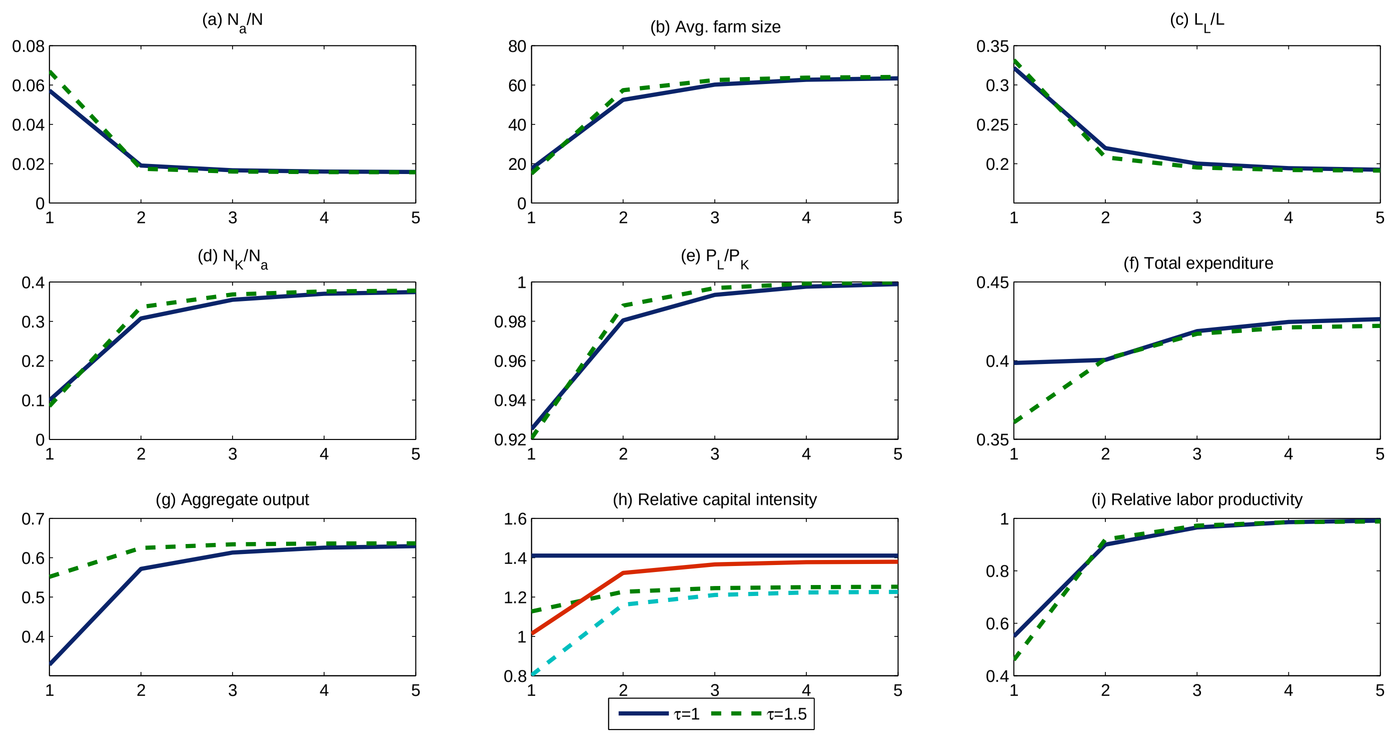
The continuous line indicates $\epsilon = 10$, the dashed line $\epsilon = 100$ and the dashed and dotted line $\epsilon = .9$. Panel (a) shows employment share in agriculture. Panel (b) average farm size. Panel (c) land share in the land intensive sector. Panel (d) agricultural employment in capital intensive sector. Panel (e) the relative price. Panel (f) relative real output. Panel (g) the relative expenditure. Panel (h) relative capital intensity in capital intensive agriculture (horizontal line) and relative capital intensity in total agriculture. Panel (i) the relative real labor productivity.

Figure 3.4: Fixed cut-offs



The continuous line shows the benchmark simulation, the dashed line the simulation with mobility barriers. Panel (a) shows employment share in agriculture. Panel (b) average farm size. Panel (c) land share in the land intensive sector. Panel (d) agricultural employment in capital intensive sector. Panel (e) the relative price. Panel (f) relative real output. Panel (g) aggregate output. Panel (h) relative capital intensity in capital intensive agriculture (continuous horizontal line), in total agriculture with fixed cut-offs (horizontal dashed line) and in total agriculture without fixed cut-offs (increasing dashed line). Panel (i) the relative real labor productivity.

Figure 3.5: Different τ



The continuous line indicates $\tau = 1$, the dashed line $\tau = 1.5$. Panel (a) shows employment share in agriculture. Panel (b) average farm size. Panel (c) land share in the land intensive sector. Panel (d) agricultural employment in capital intensive sector. Panel (e) the relative price. Panel (f) total expenditure. Panel (g) aggregate output. Panel (h) relative capital intensity in capital intensive agriculture (continuous line) and in total agriculture (dashed line). Panel (i) the relative real labor productivity.

Conclusion

The purpose of this thesis is to investigate some of the causes and consequences of high concentration of economic activity in the agricultural sector in developing countries.

In Chapter 1, we ask how international trade affects structural change in a country with large net exports of agricultural products. We argue that traditional mechanisms of structural change, under a closed economy assumption, are not able to fully account for the high share of employment in agriculture observed in this type of economy. To address this issue, we calibrate a three-sector growth model to match the patterns of structural change observed in Paraguay, a country that experienced a surge in net agricultural exports during the period 1962-2012. The model considered includes non-homothetic preferences, biased technical change, differences in capital intensity across sectors, capital accumulation and balanced international trade.

Results show that international trade is crucial to account for observed patterns of structural change in this country. The model including international trade explains 84.7% of changes in employment shares, while the model excluding trade can only account for 36.1% of changes. Moreover, the model indicates that employment in agriculture remains large in order to satisfy foreign demand of agricultural products, even as domestic consumption declines. Finally, employment shifts directly from agriculture into services, bypassing manufacturing. These findinds are reminiscent to the "premature de-industrialization" reported by Rodrik (2015), and suggest that patterns of structural change in net agricultural exporting countries can differ from the ones documented in currently advanced countries.

It is important to mention that, as shown in Section 1.2, there are only a few countries with large net agricultural exports as a percentage of GDP. However, these results are applicable to economies that simultaneously promote comparative advantage in agriculture and international trade. Such policies would lead to a high agricultural employment share at the expense of low employment in manufacturing.

In the second chapter, co-authored with Sebastian Diz, we study the consequences for monetary policy of high concentration of economic activity in agriculture. In particular, this chapter asks if it is optimal for central banks in developing countries to assign a large weight to agricultural price inflation in the Taylor rule. For this purpose, we build a multi-sector model including structural change and new Keynesian features. We consider lower-than-one income elasticity and non-unitary price elasticity in agriculture, sticky non-agricultural prices, flexible agricultural prices and sticky wages in both sectors. The model is calibrated such that developing countries have a high consumption and employment share in agriculture.

Results show that the type of shock hitting the economy is important to determine the optimal weight of agricultural inflation. After agricultural productivity shocks, it is optimal to target non-agricultural sticky prices (core inflation). However, after non-agricultural productivity shocks it is optimal to assign full weight to flexible agricultural prices. The reason is, as shown in Section 2.3.3, that under sticky wages and free labor mobility across sectors there is a link between agricultural price inflation and wage inflation. Therefore, by targeting agricultural price inflation the central bank contains wage inflation and, indirectly, non-agricultural price inflation, the two main sources of welfare loss.

The main contributions of this chapter are the following. We show how sticky wages affect the optimal measure of inflation that central banks should target. In addition, we find that welfare gains in economies with the sectoral composition of developed countries can be substantial, if central banks assign weight to agricultural inflation after shocks to non-agricultural productivity, and that this is equivalent to targeting wage inflation.

In the third chapter, co-authored with Xavier Raurich, we propose a mechanism to explain the low productivity in agriculture relative to non-agriculture observed in developing countries. We argue that changes in the sectoral composition within agriculture, in addition to structural change out of this sector, reduce the number of farmers, increases the land holdings and capital that farmers use as inputs for production. As a consequence, this process increases labor productivity in agriculture relative to that of non-agriculture. The driving forces behind this mechanism are capital accumulation, differences in capital intensity in agricultural technologies and imperfect substitution between agricultural goods. In addition, we consider labor mobility barriers and credit frictions, two sources of inefficiency documented in the literature. We find that these inefficiencies are complementary to our mechanism of structural change within agriculture in explaining low agricultural productivity in developing countries.

The contribution of the chapter is to show how preferences for agricultural products and barriers to capital accumulation within agriculture explain the high employment share and low productivity in agriculture, observed in low income countries.

Several avenues for future research can be derived from the chapters in this thesis. Regarding the first chapter, it is a well known fact that modern agriculture can coexist along subsistence agriculture in developing countries. Therefore, a further understanding of the composition of the agricultural sector is in order. Introducing this duality explicitly could help us explain how certain developing countries can employ large fractions of their workforce in subsistence agriculture and, at the same time, be productive enough to export agricultural products.

A priori, there is nothing wrong with specialization in agriculture. In fact, the finding that net agricultural exporting countries employ a large fraction of their workforce in this sector is beneficial, when the country has comparative advantage in this sector and there are no international trade distortions. However, as argued by Matsuyama (1992), specialization in agriculture could be detrimental for long-run growth, if we consider externalities present only in non-agriculture. Investigating the link between policies promoting comparative advantage in agriculture and international trade, through the lenses of endogenous growth theory, seems appropriate to improve our understanding about patterns of structural change and income in developing countries.

Regarding the second chapter, further work on the structure of the labor market is in order. In particular, relaxing the assumption of free labor mobility across sectors at business cycle frequencies and considering differences in the degree of wage stickiness are valid robustness checks for the model in this chapter. In addition, we found that the shock parameters are important drivers of our results. Therefore, investigating the empirical properties of this shocks could provide additional assurance that our findings are robust.

In the third chapter, we propose a methodology to distinguish between capital and land intensive technology in agriculture. Since we lack data on capital at crop level, we propose and indirect method. We compute the ratio between crop yields in U.S. and Spain. Since Spain converged in income and capital per worker to U.S. levels during the period 1961-2014, we should observe convergence in yields in capital intensive crops, assuming equal technologies between countries at crop level. Future work involves expanding this exercise and considering different countries, other than Spain, to account for possible institutional changes in agriculture that can explain sudden productivity increases in this sector. Finally, further empirical support on differences across countries in the elasticity of substitution between capital and land intensive agricultural goods would improve the relevance of the mechanisms outlined in the chapter.

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