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ESSAYS ON GROWTH COMPLEMENTARITY BETWEEN AGRICULTURE AND INDUSTRY IN DEVELOPING COUNTRIES

A Dissertation Presented

by

JOAO PAULO A. DE SOUZA

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

September 2015

Economics

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ESSAYS ON GROWTH COMPLEMENTARITY BETWEEN AGRICULTURE AND INDUSTRY IN DEVELOPING COUNTRIES

A Dissertation Presented

by

JOAO PAULO A. DE SOUZA

Approved as to style and content by:

J. Mohan Rao, Chair

Peter Skott, Member

James Heintz, Member

Gerald Friedman, Department Chair
Economics

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ABSTRACT

ESSAYS ON GROWTH COMPLEMENTARITY BETWEEN AGRICULTURE AND INDUSTRY IN DEVELOPING COUNTRIES

SEPTEMBER 2015

JOAO PAULO A. DE SOUZA

B.A., UNIVERSITY OF SAO PAULO

M.A., UNIVERSITY OF SAO PAULO

Ph.D., UNIVERSITY OF MASSACHUSETTS AMHERST

Directed by: Professor J. Mohan Rao

This dissertation examines three aspects of the macroeconomic role of agriculture in the industrialization of developing countries. In the first essay, I utilize instrumental variable techniques to empirically identify the effect of growth in agriculture on growth in manufacturing. Using data for 62 countries and instrumental variable techniques, I find that higher land yields in agriculture raise growth in manufacturing in the short to medium run. Along with extensions of the basic empirical model, this finding suggests that land-saving technical change can stimulate demand for industrial goods, raise fiscal revenues, and provide foreign exchange earnings to finance capital accumulation. In the second essay, I examine the role of biased-technical change in agriculture in the formation of aggregate demand for industry. I use a two-sector growth model to show that, under conditions of low factor substitutability and hidden unemployment, land-saving innovations can raise rural employment, enlarge the

domestic market for manufactures, and promote faster industrial accumulation — in contrast to labor-saving innovations. I also develop saving-constrained and open economy extensions of the baseline model. The essay casts light on a recent strand of empirical studies — including the first essay of this dissertation — which have identified a positive impact of higher land yields on industrial growth. Finally, in the third essay I develop a political-economic explanation for the labor-displacing trend that existed across the larger and most dynamic agricultural establishments in Brazil during the 1950-1980 period. Using primary data and the secondary literature, I document this trend and argue that it resulted from the interaction between public policies to promote the use of modern inputs, on the one hand, and size and power inequality across landholdings, on the other hand. As a result, the pattern of technical change in agriculture aggravated the problem of underemployment that beset Brazil's industrialization, preventing a broader distribution of its benefits.

TABLE OF CONTENTS

Page

ACKNOWLEDGMENTS . . . . . **iv**

ABSTRACT . . . . . **vi**

LIST OF TABLES . . . . . **x**

LIST OF FIGURES . . . . . **xii**

CHAPTER

INTRODUCTION **1**

1. EVIDENCE OF GROWTH COMPLEMENTARITY BETWEEN AGRICULTURE AND INDUSTRY IN DEVELOPING COUNTRIES **5**

1.1 Introduction 5
1.2 Agricultural Development and Industrialization 8
1.3 Data, Empirical Model, and Benchmark Estimates 15
1.4 Instrumental Variable Estimates 21

1.4.1 'First Stage' and Reduced Form Regressions 24
1.4.2 Baseline Results 26

1.5 Interactions and Robustness Checks 30
1.6 Potential Mechanisms 36
1.7 Conclusion 38

2. BIASED TECHNICAL CHANGE IN AGRICULTURE AND INDUSTRIAL GROWTH **43**

2.1 Introduction 43
2.2 A Medium Run Growth Model 48

2.2.1 Production and Wages 48

2.2.2 Wage Bargaining in Industry 52
2.2.3 Warranted Growth 54
2.2.4 The Effects of Technical Change in Agriculture on Industrial Accumulation 59
2.2.5 The Model in the Long Run 63

2.3 Land-Saving Technical Change in a Small Open Economy 64
2.4 Conclusion 72

3. THE POLITICAL ECONOMY OF BIASED TECHNICAL CHANGE IN BRAZILIAN AGRICULTURE (1950-1980) 76

3.1 Introduction 76
3.2 Background 80

3.2.1 The Latifundio-Minifundio System 80
3.2.2 Land Distribution and Land Use 83

3.3 The Employment Problem 85
3.4 Government Policy and Technical Change 89

3.4.1 Credit, Price, and Trade Policies 89

3.4.1.1 The Distribution of Subsidies 98

3.4.2 Research and Extension 101
3.4.3 Rural Infrastructure and Other Policies 106

3.5 Modern Inputs and Land Yields 108

3.5.1 Use of Tractors and Fertilizers 108
3.5.2 Land Yields 113

3.6 Conclusion 116

APPENDICES

A. DESCRIPTIVE STATISTICS 119
B. DATA SOURCES AND VARIABLE DEFINITIONS 121
C. PROOFS OF PROPOSITIONS 123
D. SHORT-RUN DYNAMICS 126
E. ADDITIONAL FIGURES AND TABLES 132

BIBLIOGRAPHY 137

LIST OF TABLES

Table **Page**

1.1 Benchmark estimates without temperature as an instrument. 20

1.2 'First stage' and reduced form regressions 25

1.3 Baseline estimates with temperature as instrument for agricultural growth. 28

1.4 Robustness checks and interaction effects 32

1.5 Additional robustness checks 35

1.6 Impact of agricultural growth on potential mechanisms 39

3.1 Share of total establishments, and share of total establishment area, by area group (%) 84

3.2 Share of employment categories in 1950, by area group (%). 86

3.3 Total employment across farm establishments and distribution by category 87

3.4 Bank of brazil interest rates for tractor acquisition and average market lending rates (%/year) 94

3.5 Share of cultivated land under irrigation, by area group (%) 107

3.6 Share of establishments using purchased electricity, by area group (%) 108

3.7 Indices of tractor utilization, by area group 111

3.8 Share of establishments using chemical fertilizers and lime, by area group (%) 112

A.1 Descriptive statistics of growth and temperature 119

B.1 Data sources and variable definitions 122

LIST OF FIGURES

Figure **Page**

2.1 Growth regimes 58

2.2 Technical change in agriculture in a two-gap model of a small open economy 70

3.1 Labor-land ratios by size group (in persons per 1,000 hectares of cropland and pastures). 88

3.2 Implicit tax (<0) or subsidy (>0) due to effective exchange rates (in %) 90

3.3 Total agricultural credit by the Bank of Brazil. 92

3.4 Dissemination and distribution of credit from public sources. 100

3.5 Apparent consumption of chemical fertilizers by area of cultivated land (tons/ha) 113

3.6 Area-weighted yield indices (in logarithmic scale) 118

A.1 Latitude of country geographical centers and variability in population-weighted average temperature 120

D.1 The saving-investment equilibrium with warranted growth. 129

E.1 Land use by size group (in % of total land). 133

E.2 Average number of workers per establishment, by size group (in persons per establishment). 134

E.3 Land yields by export crop (in logarithmic scale). 135

E.4 Land yields by domestic crop (in logarithmic scale). 136

INTRODUCTION

These three essays examine different aspects of an overarching question: the macroeconomic role of agriculture in developing countries. Their main premise is that agricultural development can promote the expansion of industry and modern services, and broaden the distribution of aggregate productivity gains.

The essays are self-contained and employ different methodologies. Yet they are informed by a set of unifying views. The first is the view that 'surplus' labor — labor utilizing subsistence technologies — is a pervasive phenomenon in both rural and urban areas. The second is the view that agriculture is key to the formation of aggregate demand for industry and modern services. This role is unlikely to disappear in open economies, and it complements other macroeconomic functions classically assigned to agriculture, such as the provision of fiscal revenues and foreign exchange earnings (Johnston and Mellor, 1961). It follows from these two claims that agriculture can serve a dual function as a medium-run outlet for surplus labor and a source of demand for domestic industry.

Technical innovations that raise the productivity of agriculture's basic factors of production, land and labor, are key to fulfilling this dual function. But the third view that informs these essays is that these innovations are most often biased — they affect the relative productivity of land and labor as much as their absolute productivity. Under the technical conditions of developing-country agriculture, these biased innovations have asymmetrical effects on output and employment. Land-saving innovations normally raise both output and employment, whereas labor-saving innovations seldom raise output and often reduce employment.

Finally, the fourth view is that, rather than being optimal responses to the relative scarcity of land and labor, the observed factor-saving biases are most often a result of the political economy of rural development. The interaction between size and power inequality across landholdings, on the one hand, and public policies for input prices, credit, and rural infrastructure, on the other hand, are key to determining the availability and the adoption of technical innovations. Depending on this interaction, the pattern of technical change in agriculture may lead to considerable labor displacement, aggravating the problem of surplus labor and narrowing the domestic market for industrial goods.

In other words, all three essays share a common scope in medium-run scenarios characterized by surplus labor, and a common focus on how technical innovations in agriculture can promote or hinder industrial growth in these scenarios. As a corollary, the essays place little emphasis on long-run scenarios in which labor shortages could emerge.

The first essay, titled *Evidence of Growth Complementarity Between Agriculture and Industry in Developing Countries*, is concerned with the empirical identification of macroeconomic complementarity between the two sectors. Using dynamic panel models with data for 62 developing countries, it examines whether growth in agriculture elicits growth in manufacturing. For identification, it uses population-weighted, average temperature as an instrument for growth in agriculture, exploring exogenous variation in land yields that resemble the effects of land-saving innovations. It finds large short-run effects: a one-percentage point increase in growth in agriculture is estimated to raise growth in manufacturing by 0.47-0.56 percentage point (baseline), and 0.28-0.47 percentage point (conservative). Extensions of the empirical model suggest that growth in agriculture benefits the manufacturing sector by improving its domestic terms of trade, by increasing the share of investment and saving in GDP, and by increasing the capacity to import industrial inputs. Together, these findings

lend support to the notion that agriculture plays key macroeconomic roles in the industrialization of developing countries by relieving aggregate demand, fiscal, and foreign exchange constraints on the industrial sector.

The second essay, titled *Biased Technical Change in Agriculture and Industrial Growth*, is primarily concerned with the role of biased-technical change in agriculture in the formation of aggregate demand for industry. It presents a two-sector growth model in which industrial accumulation is sensitive to the factor-saving bias of technical change in agriculture. By embodying structural characteristics common to several developing countries — especially low factor substitutability and hidden unemployment in agriculture — the model shows that land-saving innovations can raise rural employment and income, enlarge the domestic market for manufactures, and promote faster industrial accumulation, in contrast to labor-saving innovations. The essay also presents saving-constrained and open economy extensions of the baseline model. Together, these contributions cast light on a recent strand of empirical studies — including the first essay of this dissertation — which have identified a positive impact of higher land yields on industrial growth. They also cast light on historical accounts of the role of biased agricultural innovations in the early industrialization of Japan, East Asia, and Latin America.

Finally, the third essay, titled *The Political Economy of Biased Technical Change in Brazilian Agriculture (1950-1980)*, contributes a political-economic explanation for the labor-saving bias of technical change in Brazilian agriculture during a key period in the country's industrialization. Using primary data and the secondary literature, it establishes that a strong labor-displacing trend existed across the larger and most dynamic agricultural establishments until the 1970s. It then examines how public policies to promote the use of modern inputs — such as price and credit subsidies, research and extension, and rural infrastructure — interacted with size and power inequality across landholdings to impart a marked labor-saving bias to

technical change. As a result, Brazilian agriculture failed to provide a productive medium-run outlet for surplus labor, aggravating the problem of rural and urban underemployment and preventing a broader distribution of the benefits of industrial growth.

CHAPTER 1

EVIDENCE OF GROWTH COMPLEMENTARITY BETWEEN AGRICULTURE AND INDUSTRY IN DEVELOPING COUNTRIES

1.1 Introduction

There is little doubt that the expansion of industrial activities and their ancillary services characterizes sustained episodes of economic growth in developing countries.[1] But the initial stages of industrialization almost invariably impinge on societies where agriculture accounts for a large share of output and employment.

Several recent studies have underscored the role of agriculture in generating favorable initial conditions for modern economic growth. Their dominant theme is the historical pattern of land ownership and its lasting influence on the distribution of income and education, on the incidence of social conflict, and on the development of institutions of economic and political governance.[2]

And yet, beyond the lasting political-economic influence of agrarian structure, agriculture also plays macroeconomic roles in industrialization. They include providing saving and foreign exchange to finance capital accumulation, as well as a home market for industry (Johnston and Mellor, 1961). Their fulfillment is a key ingredient of successful industrialization, as recognized by Alice Amsden in regard to Taiwan's post-war experience:

---

[1]For recent evidence on the relation between structural change and economic development, see Timmer and Vries (2009), Ocampo et al. (2009), and McMillan and Rodrik (2011).

[2]For recent examples, see Engerman and Sokoloff (2002), Acemoglu et al. (2000, 2005), Galor et al. (2009), and Oyvat (2013).

> Agriculture managed to produce a food supply sufficient to meet minimum domestic consumption requirements as well as a residual for export. [...] Good rice harvests have been a major factor behind price (and real wage) stability. [...] Agriculture also managed to provide an important source of demand for Taiwan's industrial output, particularly chemicals and tools, and a mass market for consumption goods. [...] In summary, agriculture in Taiwan gave industrial capital a labor force, a surplus, and foreign exchange. (Amsden, 1979, p. 363)

This paper estimates whether growth in agriculture elicits growth in manufacturing, providing reduced-form evidence of macroeconomic linkages between the two sectors. Using average temperature to identify changes in agricultural supply in 62 developing countries, I estimate that a one percentage point increase in growth in agriculture raises contemporaneous growth in manufacturing by between 0.47 and 0.56 percentage point in the baseline specifications, and by between 0.28 and 0.47 percentage point in more conservative specifications that limit influential observations.

As discussed below, annual variation in temperature is best suited to identify short-run effects. Still, the implied long-run multipliers show that if the average country in the sample were to permanently increase growth in agriculture to 4.4%/yr (the average in China during 1961-2006), growth in manufacturing would eventually increase by between 0.95 and 1 percentage points. This effect is substantial, as the sample mean of growth in manufacturing is 4.5%/yr.

Estimating the effect of growth in agriculture using country-level data is challenging for two main reasons. First, countries differ along time-constant dimensions, such as natural conditions, that are correlated with growth in agriculture. To address this problem, I control for country fixed effects, using only relative variation within countries to identify the coefficients.

Second, regressions relating growth in the two sectors are likely to run afoul of bias due to reverse causality and omitted time-varying variables. To address these problems, I control for the previous dynamics of growth in manufacturing, and use a

population-weighted measure of average annual temperature (from Dell et al., 2012a) as an instrument for growth in agriculture.

A growing body of evidence has shown that annual variation in average temperature is an important determinant of crop yields under the technical and geographical conditions of most developing countries (see section 1.4). This fact makes my empirical strategy appealing, as it exploits a source of variation in agricultural growth that resembles the effect of yield-increasing innovations — a type of technical change that characterized agricultural development during the early industrialization of Japan and East Asia, and later spread to other countries as part of the 'green revolution'.

This paper joins a growing literature using climate data to identify supply shocks in agriculture (see Dell et al., 2013, for a broad review). It is particularly related to papers that have used this identification strategy to establish causal relations between agricultural growth and broader economic outcomes, such as local urban activity (Henderson et al., 2009), patterns of migration (Brückner, 2012), and industrial growth (Shifa, 2015).

This empirical strategy also assumes that annual variation in average temperature within countries, while exogenously shifting agricultural supply, does not directly affect growth in manufacturing. Section 1.4 below further discusses the appropriateness of this assumption.

Besides estimating the reduced-form effect of growth in agriculture on growth in manufacturing, I explore a number of potential mechanisms that could explain it. I find that growth in agriculture improves the domestic terms of trade of the non-agricultural sector, increases the share of investment and saving in GDP, increases the capacity to import industrial inputs, and increases average output per worker.

These two contributions lend support to the notion that agriculture plays key macroeconomic roles in the industrialization of developing countries by relieving saving, aggregate demand, fiscal, and foreign exchange constraints on the industrial

sector. In particular, they suggest that the assumptions typically required to generate a trade-off between yield-increasing innovations in agriculture and industrial development — such as perfect tradability and full employment — are unlikely to hold in most developing countries, at least in the short to medium run (see sections 1.2 and 1.7 for further discussion).

The paper is organized as follows. Section 1.2 motivates the question in relation to the existing empirical and theoretical literature. Section 1.3 describes the dataset and introduces the empirical model. Section 1.4 discusses the identification strategy and presents the main empirical results of the paper: the effect of growth in agriculture on growth in manufacturing using temperature as an instrumental variable. Section 1.5 examines the effects of controlling for cross-country heterogeneity along several dimensions — such as the share of agriculture in GDP and the degree of openness to international trade —, as well as several robustness checks; Section 1.6 examines the impact of agricultural growth on potential channels through which it would enhance industrial growth. Section 1.7 discusses the main findings, implications, and limitations of the paper. Appendices A and B provide descriptive statistics and detailed variable definitions.

1.2 Agricultural Development and Industrialization

Most of the recent empirical literature consists of reduced-form tests of whether output or productivity growth in agriculture bolster their counterparts in other sectors. To address reverse causality and omitted variable bias, most authors have deployed time series techniques or instrumental variables.

For example, a group of studies has used cointegration and error correction models to estimate long-run sectoral balance relations, followed by an examination of sectoral responses to deviations from this equilibrium. Studies of individual countries have yielded mixed results: Gemmell et al. (2000) found that manufacturing output and

productivity in Malaysia were exogenous (in the sense of Granger) to increases in their counterparts in agriculture. By contrast, Kanwar (2000), and Chebbi and Lachaal (2007) found that they responded positively in India and Tunisia. A study of panel cointegration using a sample of 85 countries, however, confirmed the finding of positive responses for the majority of countries in the sample (Tiffin and Irz, 2006).

By contrast, this paper follows an alternative, but increasingly common strategy: the identification of exogenous shifts in agricultural value added from variation in climate variables, such as rainfall and temperature (Dell et al., 2013). Some of these studies examine the regional impact of growth in agriculture. For example, Henderson et al. (2009) find that the intensity of city lights at night increases in years of favorable rainfall in adjacent rural areas. Their results, derived from satellite images of 541 cities in 18 African countries, indicate substantial local complementarity between the rural and urban economies.

But macroeconomic complementarity can be better discerned at a higher level of aggregation. To that end, Dell et al. (2012a) build average measures of nationwide temperature and rainfall, using local population as weights. They find that GDP growth declines in poor countries when temperature is higher than the historical average.

Changes in agricultural yields are the channel most likely to explain these reduced-form relations between climate variables and economic growth. Several authors have therefore used country-level climate variables as instruments for output and productivity in agriculture. For example, using precipitation as an instrumental variable (along with international commodity prices), Brückner (2012) finds that lower value added in agriculture leads to distress migration and the expansion of urban informal activities. In turn, using temperature and precipitation as instrumental variables, Shifa (2015) finds that higher growth in agriculture elicits sizable short-run increases in growth in manufacturing in a large sample of countries.

The empirical findings above raise a natural question: what macroeconomic mechanisms explain the observed complementarity between agricultural and industrial development? The answer is that agriculture can ease saving, demand, foreign exchange, and fiscal constraints on industrial accumulation. These roles of agriculture have been explored in a number of previous contributions.

Traditional development theory, for example, saw the availability of domestic saving as the main constraint on the rate of capital accumulation. Many authors thus called on agriculture to elicit higher saving from the private non-agricultural sector, in particular by lowering unit costs in industry. This understanding of agriculture as a source of surplus to finance industrialization set the stage for classic debates, especially on the role of intersectoral terms of trade in Soviet and South Asian industrialization (see, e.g. Preobrazhensky, 1965; Ellman, 1975; Sah and Stiglitz, 1984; Mitra, 2005).

Agriculture's role in increasing the investible surplus in a market economy is predicated on three notions: first, that most saving originates in retained profits and other non-wage incomes; second, that unit costs are a key determinant of real industrial saving in terms of its own output; and, third, that in dual economies agricultural labor productivity is a key determinant of industrial unit costs.

Arthur Lewis laid out the classical model outlining the macroeconomic mechanisms behind this view. By linking money wages in industry to the value of the average product in agriculture, Lewis suggested that agricultural development will raise industrial accumulation if the fall in agriculture's domestic terms of trade dominates the increase in industrial wages in terms of food (Lewis, 1954, p. 173-176). The presence of Engel's Law in final demand — the proposition that the share of primary goods in total expenditure falls as income increases — is crucial to ensure this result in a market economy (Jorgenson, 1961).

The notion that private saving is the binding domestic constraint on industrial growth has been challenged on two fronts: by those emphasizing fiscal constraints on complementary public investment, and by those emphasizing insufficient domestic demand.

Public infrastructure and private investment may be bound by direct technical complementarity in industrializing economies. Expected demand may justify private projects, yet investors may fail to undertake them in the absence of complementary public investment in energy or transportation.[3] In addition, infrastructure is often subject to increasing returns to scale and market failures, and it is largely non-tradable. These characteristics hinder the ability of private investors to sustain the required level of infrastructural investment (Skott and Ros, 1997).

Agriculture, as it turns out, has often been a prominent source of fiscal revenues in industrializing economies. For example, the direct taxation of agricultural rents was key for funding infrastructure investment during the first several decades of Japan's industrialization (Ohkawa and Rosovsky, 1960). But due to technical or political constraints, in most post-war episodes of industrialization governments resorted to instruments of indirect taxation, such as trade tariffs and quotas, multiple exchange rates, and domestic marketing boards. As a result, wedges between the actual terms of trade of agriculture and border prices were common, with governments often capturing the implied transfers as fiscal or quasi-fiscal revenues (Peterson, 1979; Oliveira, 1985; Rao, 1989; Schiff and Valdés, 1998). The importance of these mechanisms in generating fiscal revenues became evident in the wake of recent episodes of market liberalization across the developing world, which often worsened fiscal constraints (Khattry and Rao, 2002; Baunsgaard and Keen, 2010).

[3]For empirical evidence concerning developing countries, see Belloc and Vertova (2006), Romp and De Haan (2007), and Canning and Pedroni (2008).

In turn, domestic demand may fail to justify private investment projects, and international trade may afford scarce possibilities to offset this shortfall, especially in the short-run. Private investment may thus be deficient even without an *ex ante* saving shortfall, causing the economy to come under a Keynesian aggregate demand constraint.

A number of two-sector models in the post-Keynesian and Structuralist traditions have shown that technical progress in agriculture can relieve demand constraints on industrial accumulation. In common, they posit that firms make independent investment decisions with an eye to expected profitability, and that mechanisms — such as changes in functional distribution or capacity utilization — exist to endogenously bring *ex-post* saving into line with desired investment. Agriculture can be a source of autonomous demand for industry by purchasing industrial inputs and, in the presence of Engel's effects, by reducing the cost to workers of meeting their income-inelastic demand for food (see, e.g.: Taylor, 1982, 1983; Dutt, 1992; Rao, 1993; Skott, 1999).

The channels of complementarity above, however, have been called into question for open economies. Matsuyama (1992) proposed an influential Ricardo-Viner model of a small open economy characterized by full employment. He shows that higher productivity in agriculture elicits a reallocation of labor away from industry, reducing domestic industrial production and, through a standard learning-by-doing mechanism, the long-run growth of labor productivity in industry.

Matsuyama (1992) only considered neutral technical change. In turn, Bustos et al. (2012) extended the original framework to consider factor-saving biases, given that some forms of technical change are primarily land-saving (e.g. multiple cropping, high-yielding varieties, irrigation, and fertilizers), while other forms are primarily labor-saving (e.g. the mechanization of sowing, harvesting, and threshing). Where the stock of effective land is the main constraint on output, and the elasticity of substitution between land and labor is low, land-saving technical change raises labor

absorption into agriculture, while the converse is true of labor-saving technical change (see, e.g., Johnston and Cownie, 1969; Ruttan, 1977; Otsuka et al., 1994; Hossain et al., 2006, for a discussion of the empirical evidence).

By adding biased technical change to a Matsuyama-type model, Bustos et al. (2012) show that land-saving technical change causes workers to relocate to agriculture, at the expense of industrial employment and output. By contrast, labor-saving innovations cause workers to leave agriculture, and a competitive labor market ensures that they are taken up by industry. This strand of the literature thus suggests that innovations biased towards increasing land yields are likely to entrench historical patterns of comparative advantage in primary sectors, hindering long-term industrial development.[4]

In contrast to this prediction, I find that growth in agriculture — identified through exogenous yield increases — benefits industry, at least in the short to medium run. This finding suggests that the assumptions required by Matsuyama (1992) and Bustos et al. (2012) to generate the opposite result are unlikely to hold in the average developing country over this time frame.

There are three such assumptions. The first is perfect tradability in both agriculture and industry. In a small open economy this assumption fixes the intersectoral terms of trade exogenously at the level of world prices. And, indeed, if the terms of trade are unresponsive to agricultural growth, neither supply-side complementarity in a Lewisian framework nor demand-side complementarity in a Keynesian framework will obtain. For example, higher labor incomes in agriculture will now directly raise unit labor costs in terms of the industrial good in a simple Lewisian model, slow-

[4]Bustos et al. (2012) find empirical support for their model using municipal data for Brazil. The use of subnational data, however, couches the test under conditions that most closely resemble those of small open economies (especially with regard to the the exogeneity of intersectoral relative prices). This fact, along with the results in the present paper, casts doubt on the extent to which their conclusions could carry over to national economies.

ing down accumulation (Skott and Larudee, 1998). As Matsuyama (1992) himself admits, however, perfect tradability is an extreme notion. Detailed case studies of intersectoral resource flows indeed suggest that, in a world of trade restrictions and non-tradable subsectors, periods of technical dynamism in agriculture often correlate with endogenous declines in the sector's domestic terms of trade (see, e.g. Mellor, 1973; Karshenas, 1995, and section 1.5 below).

The second assumption is that factor substitutability in industry and a competitive intersectoral labor market lead to full employment. But hidden unemployment in both rural and urban areas is a defining feature of developing countries, indicating that, with imperfect factor substitutability in production and labor market failures, the size of the capital stock in the modern sector is the effective constraint on modern employment. Thus, greater labor absorption into agriculture in the short to medium run need not come at the expense of industry.

The third and last assumption is the absence of a foreign exchange constraint on the ability of domestic industrial investment to absorb *ex ante* domestic saving. The Ricardo-Viner trade structure of Matsuyama's model implies that trade at world prices remains balanced despite the fact that a reallocation of labor to industry may cause agricultural exports to contract. As it turns out, however, industrialization in developing countries is likely to require a high coefficient of imported intermediate and capital goods. As a result, as the industrial sector grows and diversifies, its net foreign exchange requirements may rise in the short to medium run. Accumulation may thus be constrained by insufficient foreign exchange earnings in the face of limited ability to run persistent current account deficits (Chenery and Bruno, 1962; Bacha, 1990; Taylor, 1994). Moreover, there is no evidence that exchange rate adjustment can smoothly correct these deficits in the absence of contractionary policies, which hurt industrial growth (Chinn and Wei, 2013; Ocampo, 2003).

Under a binding foreign exchange constraint, agriculture can bolster industrial accumulation by producing crops for export or by reducing food imports. Agriculture's ability to relax a foreign exchange constraint is therefore a fourth macroeconomic channel of complementarity, in addition to its ability to relax saving, demand, and fiscal constraints. Indeed, by examining intermediate import demand in a dependent economy framework that eschews the three main assumptions above, Rattsø and Torvik (2003) show that agricultural development and industrial growth can remain synergistic in open economies.

To be sure, the evidence produced by my empirical strategy was obtained on the basis of short-run variation in the instrument. The estimates therefore fail to account for changes in the relationship between agriculture and industry which could follow in the wake of prolonged episodes of growth. In particular, the emergence of labor shortages would eventually call for a labor-saving bias in technical change in agriculture (although this bias should be seen as induced by industrial growth, not as an independent cause of it). For further discussion of the scope and limitations of the findings, see section 1.7.

1.3 Data, Empirical Model, and Benchmark Estimates

My empirical model uses sectoral value added data from the World Development Indicators (WDI). I exclude developed and transition economies, as well as countries with less than one million inhabitants. I also exclude countries with less than 25 consecutive observations, to mitigate inference distortions caused by short panels (I relax some of these constraints to check the robustness of the results, see section 1.5).

The resulting unbalanced panel boasts 62 countries, spans the 1960-2006 period, and has on average 36 observations per country[5].

As shown in table A.1 in Appendix A, the sample mean of growth in agriculture is quite low: 2.6%/yr. Agricultural growth is also volatile, with an overall standard deviation of 8.6%. At 4.5%/yr, the sample mean of growth in manufacturing is higher, but also volatile, with an an overall standard deviation of 8.5%. Perhaps surprisingly, a standard decomposition attributes most of this volatility to variation in growth within countries, as opposed to variation in growth across countries. In other words, most countries achieve high growth in both sectors, but few sustain it over time. Growth volatility is especially pronounced in Sub-Saharan Africa.

The regressions estimated in this paper follow a dynamic panel specification which allows for the propagation of short-run variation in agricultural growth over time

$$\Delta ln(\mathrm{VA}_M)_{i,t} = \beta_0 + \sum_{n=1}^{p} \alpha_n \Delta ln(\mathrm{VA}_M)_{i,t-n} + \sum_{j=0}^{q} \beta_j \Delta ln(\mathrm{VA}_A)_{i,t-j} + \gamma Z_{i,t} + \epsilon_i + \epsilon_t + \epsilon_{i,t} \tag{1.1}$$

where VA_M and VA_A denote real value added in manufacturing and agriculture. The subscripts i and t index countries and years, Δ denotes first differences, and $Z_{i,t}$ denotes a vector of controls. As is standard in panel data analysis, the baseline model decomposes the unobserved residual into a time-constant portion that is specific to each country (ϵ_i), a time-varying portion that is common to all countries (ϵ_t), and a time-varying portion that is specific to each country ($\epsilon_{i,t}$).

By including lags of the dependent variable, the specification in (2.2) controls for the past dynamics of growth in manufacturing. Estimating it using the standard 'within' estimator thus addresses two sources of bias. First, it controls for idiosyn-

[5]Although the WDI dataset goes beyond 2006, that is the last year for which measures of population-weighted temperature are available. To ensure comparability across specifications, I restrict the sample to 1960-2006 in all models.

cratic country characteristics correlated with the performance of agriculture; second, it ensures that growth in agriculture is conditionally uncorrelated with past growth in manufacturing.

Still, a causal interpretation of the coefficients requires the assumption that growth in agriculture is uncorrelated to the contemporaneous and lagged error terms, conditional on past growth in manufacturing, the country and year fixed effects, and any other covariates included in $Z_{i,t}$:

$$E[\epsilon_{i,t}\Delta ln(\mathrm{VA}_A)_{i,s}] = 0, \ \forall \ s \leq t \tag{1.2}$$

The assumption in (1.2) is likely to fail due to omitted variable bias, motivating the use of temperature as an instrument for growth in agriculture. Before describing those estimates, however, it is useful to establish benchmarks — based on the identifying assumption in (1.2) — against which to compare them. This section describes two such benchmarks. The first is obtained by estimating equation (2.2) with annual data and the within estimator. The second is obtained by estimating it with growth in manufacturing over non-overlapping five-year periods, in order to establish a medium-term association that does not use annual variation for coefficient identification.

Columns (1)-(3) in table 1.1 show the model in (2.2) estimated with annual data and the within estimator. Each specification includes two lags of growth in manufacturing[6]. Column (1) only includes contemporaneous growth in agriculture which, as we can see, has a positive and statistically significant association with growth in manufacturing. But this contemporaneous effect is small: an increase in agricultural growth by one percentage point is a associated with an increase in growth in manufacturing of only 0.10 percentage point. Columns (2) and (3) include up to three

[6]Deeper lags were never statistically significant, and their inclusion did not alter the results.

lags of growth in agriculture. Only the first two lags are positive and individually significant (deeper lags are also insignificant, but they are not reported).

The dynamic specifications in columns (1)-(3) allow us to compute cumulative effects by assuming a permanent increase in growth in agriculture.[7] As table 1.1 shows, the estimated long-run multipliers are statistically significant — the multiplier in column (2) implies that a permanent increase in growth in agriculture by one percentage point is associated with an increase of 0.32 percentage point in growth in manufacturing after enough years elapse.

The empirical model allows for both fixed effects and lags of the dependent variable. The within transformation therefore creates a mechanical correlation between the lagged dependent variable and the error term (Nickell, 1981). The resulting bias converges to zero as the number of time periods increase, so it is unlikely to be large given the average of 36 observations per country. Still, to address this potential problem, column (4) shows the specification in column (2) estimated using a system GMM procedure in the spirit of Arellano and Bond (1991), and Arellano and Bover (1995). The procedure applies forward orthogonal deviations to the variables in order to eliminate panel-specific fixed effects, using lags of the untransformed variables as instruments for the transformed variables. The identifying assumption is:

$$E[\epsilon^*_{i,t+1}(\Delta ln(\mathrm{VA}_M)_{i,s-1}, \Delta ln(\mathrm{VA}_A)_{i,s})'] = 0, \ \forall \ s \leq t \tag{1.3}$$

where $\epsilon^*_{i,t+1}$ indicates the forward orthogonal deviation of $\epsilon_{i,t}$.[8] If there is no autocorrelation in the error term of second (or higher) order, the first (and deeper) lags

[7]The long-run multiplier that embodies this assumption of a permanent increase is given by $\sum_{j=0}^{q} \beta_j (1 - \sum_{n=1}^{p} \alpha_n)^{-1}$, where β_j and α_n are the coefficients on growth in agriculture and manufacturing, and q and p are the respective number of lags, as defined in (2.2).

[8]The time subscript reflects the practice of storing orthogonal deviations one period late, for consistency with other commonly used transformations, such as first differences (Roodman, 2006). In other words, $\epsilon^*_{i,t+1} = c_{i,t}(\epsilon_{i,t} - T_{i,t}{}^{-1} \sum_{j=t+1}^{T_{i,t}} \epsilon_{i,t})$, where $T_{i,t}$ indicates the number of available future observations, and $c_{i,t} = \sqrt{T_{i,t}/T_{i,t}+1}$ is a scaling factor.

of the variables in levels are valid instruments for the transformed lagged dependent variables.[9] The existence of second-order autocorrelation in the error term can be tested using the data, but a causal interpretation of the coefficients on agricultural growth still hinges on the assumption in (1.2). The coefficients on agricultural growth show a small decline with the system GMM procedure, but growth in manufacturing shows greater persistence, so that the long-run multiplier declines only slightly.

Columns (5)-(7) present the second set of benchmark estimates, which modify the empirical model in two ways. First, I measure growth in manufacturing over non-overlapping five-year periods, starting with 1960-1965 (I annualize the result for ease of interpretation). Second, I decompose the right-hand-side variables into two types: a set of 'flow' variables measured as annual averages over each growth period, including growth in agriculture; and a set of 'stock' variables measured at the beginning of each growth period (see Caselli et al., 1996, for further discussion of this specification).

Since the transformed dataset has few time periods, I estimate all the specifications using the Arellano-Bond-Bover procedure. The specification in column (5) includes only period dummies and one lag of the dependent variable, in addition to growth in agriculture. In turn, the specifications in columns (6) and (7) attempt to attenuate omitted variable bias by including two different sets of flow and stock variables. These variables capture external and domestic macroeconomic conditions, such as the initial level of GDP per capita and the external terms of trade (for a detailed description of the variables in each set, see table B.1 in Appendix B). As we can see, the estimates in columns (6) and (7) imply that an increase by one percentage point in average growth in agriculture is associated with an increase in annual growth in manufacturing of

[9]The system GMM approach also estimates equations with the untransformed variables, now using lags of the transformed lagged dependent variables as instruments. These instruments are by construction purged of correlation with the unobserved fixed effects, and it is also assumed that they are uncorrelated with other components of the contemporaneous error term. The use of these additional moment conditions to estimate a 'stacked' system is shown to increase efficiency (Arellano and Bover, 1995).

Table 1.1: Benchmark estimates without temperature as an instrument.

					Model with five-year averages		
	(1) OLS/FE	(2) OLS/FE	(3) OLS/FE	(4) SGMM	(5) SGMM	(6) SGMM	(7) SGMM
Δ ln (Agr. V.A.)	0.116***	0.143***	0.145***	0.116**	0.592***	0.491***	0.527***
	(0.041)	(0.044)	(0.044)	(0.047)	(0.143)	(0.137)	(0.161)
Δ ln (Agr. V.A.)$_{t-1}$		0.109***	0.114***	0.094***			
		(0.030)	(0.030)	(0.031)			
Δ ln (Agr. V.A.)$_{t-2}$		0.060***	0.071***	0.051**			
		(0.021)	(0.024)	(0.022)			
Δ ln (Agr. V.A.)$_{t-3}$			0.031				
			(0.023)				
Country FE	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y
Controls	N	N	N	N	N	set 1	sets 1+2
$\sum \Delta$ ln (Agr. V.A.)	0.116	0.312	0.361	0.261	0.592	0.491	0.527
p-value	0.007	0	0	0.001	0	0.001	0.002
Lags of Δ ln (Man. V.A.)	2	2	2	2	1	1	1
$\sum \Delta$ ln (Man. V.A.)	0.054	0.028	0.048	0.082	0.187	0.130	0.084
p-value	0.331	0.615	0.269	0.145	0.032	0.118	0.280
Long-run Multiplier	0.123	0.321	0.380	0.284	0.728	0.565	0.576
p-value	0.008	0	0	0	0	0.001	0.004
Num. of GMM Instruments				52	14	20	33
Lags of GMM Instruments				2	2	2	2
AR(2) test (p-value)				0.331	0.343	0.323	0.168
Hansen test (p-value)				0.182	0.158	0.683	0.242
Countries	62	62	62	62	62	55	55
Avg. Obs. per Country	36.048	35.952	35.194	35.952	6.226	6.309	6.309

*** p<0.01, ** p<0.05, * p<0.1

Notes: The dependent variable is growth in real value added in the manufacturing sector. Standard errors robust to arbitrary forms of correlation within countries are in parentheses. Columns labeled "OLS/FE" indicate the fixed-effects estimator, while columns labeled "SGMM" indicate the Arellano-Bover-Bond system GMM estimator (see description in the text). All specifications include a set of year or period dummies. The specifications in columns (6) and (7) also include the sets of control variables described in the text (for detailed variable definitions for each set, see Appendix B). The SGMM estimates of the specifications in columns (5)-(7) were obtained using two lags of the lagged dependent variable and of all all endogenous flow variables (with the exception of the external terms of trade) as instruments for the transformed equation. The instrument matrix was collapsed to avoid instrument proliferation (Roodman, 2009).

between 0.49 to 0.52 percentage points over a five-year period. These medium-run estimates exceed the corresponding short-run OLS estimates obtained using annual data, as well as the sum of lagged coefficients in columns (2) or (4). I consider these to be the benchmark medium-run estimates obtained without external instrumental variables.

1.4 Instrumental Variable Estimates

The benchmark estimates above address important sources of bias, but in order to obtain causal estimates one needs a source of variation in agricultural output that is uncorrelated with relevant omitted variables. Dell et al. (2012a) provide a candidate instrumental variable for growth in agriculture: annual variation in country-level average temperature.

To construct their measure, Dell et al. (2012a) aggregated monthly local temperature measurements available in the larger Terrestrial Air Temperature and Precipitation Gridded Monthly Time Series dataset (Matsuura and Willmott, 2009). The original measurements were interpolated from a number of weather stations, and then made available on a spatial grid with a resolution of 0.5^ox0.5^o of latitude and longitude (at the equator, each grid node corresponds to approximately 56km^2). Dell et al. (2012a) weighted these local measurements by local population, using a survey conducted by the Global Rural-Urban Mapping Project in 1990 (CIESIN et al., 2004). This weighting scheme rests on the assumption that land near populated areas is cultivated more intensively than land in remote areas. Other weighting schemes yielded little change to the authors' estimates of the reduced-form impact of temperature on a number of economic outcomes (Dell et al., 2012b).

The evidence shows that higher-than-average temperature hurts crop yields under the geographical and technical conditions of most developing countries. Controlled agricultural experiments found that increased air temperature shortens crucial crop growth stages, and increases evapotranspiration and water use (see, e.g. Adams et al., 1990; Mendelsohn et al., 2000; Parry et al., 2007). Although these effects are nonlinear, most of the countries in the sample are located in the intertropical region, where average temperature is relatively high.[10] In addition, many developing countries

[10]Indeed, the geographical centers of 70% of the countries in the baseline sample are located in the intertropical region, and the geographical centers of all but one of the remaining countries are

have used relatively backward technologies in agriculture, curbing farmers' ability to respond effectively to climate variation.

As a result, studies linking temperature to crop yields through reduced-form specifications — which, unlike controlled experiments, allow for short-run adaptation on the part of farmers and policy-makers — suggest a negative causal relation between higher-than-average temperature and crop yields in developing countries. This relation is often muted or absent among developed countries (Deschenes and Greenstone, 2007; Guiteras, 2009; Dell et al., 2012a). My findings described below are in line with this broader literature.

Furthermore, in light of the evidence above my empirical strategy explores a source of variation in agricultural growth that resembles the effect of yield-increasing technical innovations, such as irrigation and water control, multiple cropping, high-yielding varieties, and fertilizers. My results thus suggest the benefits that this type of technical progress can confer on industry (see section 1.7 for further discussion).

The instrumental variable estimates in this section maintain the following identifying assumption:

$$E[\epsilon_{i,t} \ln(\text{wtem})_{i,s}] = 0, \ \forall \ s \leq t \tag{1.4}$$

where $\ln(\text{wtem})_{i,s}$ denotes the log of population-weighted temperature, and all variables embody either the within transformation or forward orthogonal deviations.

Even though there is no question that annual variation in a country's average temperature is exogenous to growth in manufacturing and agriculture, one may claim that it could affect growth in the manufacturing sector through unobserved channels unrelated to agriculture, violating the exclusion restriction in (1.4).

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located in the subtropical region (between the tropics and parallels 38 N and 38 S). See Figure A.1 in Appendix A

In particular, controlled experiments have documented a decline in measures of worker productivity in non-agricultural activities with high temperatures (Seppänen and Vuolle, 2000; Seppänen et al., 2006). These controlled experiments find that large increases in air temperature are required for perceptible declines in productivity — for example, a 6^oC increase in temperature from a neutrality threshold of 25^oC is required to cause a 10% decline in quantifiable measures of worker performance (Seppänen et al., 2006).

The empirical model of this paper, however, relies only on deviations of a country's annual temperature from its long-term average for coefficient identification. As seen in table A.1 and figure A.1 in Appendix A, large annual swings in a country's average temperature are implausible. The overall within-country standard deviation is only 0.5^oC, with imperceptible differences across regions. The average interquartile range, in turn, is 0.67^oC, and the average range between the maximum and the minimum mean annual temperature recorded is 1.97^oC. These figures fall to 0.55^oC and 1.67^oC among the warmest countries (those with a median average temperature equal to or greater than 25^oC). Moreover, by virtue of their controlled design, studies of the effect of temperature on worker productivity fail to account for organizational adaptations that, over the course of a year, could offset the effects of unusually high temperatures given a region's historical record.

To be sure, it is possible that large but localized swings in temperature could have perceptible effects on local non-agricultural output (see, e.g. Zivin and Neidell, 2010, for a study using local U.S. data collected at daily frequency). But it is difficult to claim that aggregate variation in the dataset is systematically driven by such extreme, localized events.

Given that it is impossible to test the exclusion restriction in (1.4), the results should be interpreted with caution. Still, in section 1.5 I present specifications that limit the range of variation in temperature used for identification, in addition to

specifications that control for other potential violations of (1.4). The main results are robust to these changes in the baseline model.

1.4.1 'First Stage' and Reduced Form Regressions

Columns (1)-(4) in table 1.2 examine changes in population-weighted average temperature as exogenous shifters of countrywide agricultural supply. They show fixed-effects regressions of growth in agriculture against up to three lags of the logarithm of contemporaneous temperature ($ln(wtem)_{i,t}$). Year dummies and two lags of growth in manufacturing are also included, since they are part of the structural model of interest.

All specifications show a negative contemporaneous effect of higher temperature on growth in agriculture. The effect is practically large and statistically significant. An increase in average temperature of one 'within' standard deviation (about 0.025 log points, or 0.5^o C) is predicted to cut between 0.82 and 1.17 percentage points of the contemporaneous growth rate in agricultural value added, according to the estimates in columns (1) and (2). This is a large short-run decline, as the unconditional mean of agricultural growth is only 2.6%/yr.

The specifications in columns (2)-(4) add deeper lags of average temperature. As we can see, as temperature returns to its long-run average after a shock, crop yields tend to return to normal. This fact is shown in the positive and significant coefficient of the second lag of temperature — i.e.: holding contemporaneous average temperature constant, higher temperature in the previous year is expected to increase agricultural growth in the current year. Deeper lags of average temperature are statistically insignificant, suggesting that the effect of a one-off temperature shock on agricultural growth is confined to the short run.[11]

[11] Alternative specifications allowing for non-linear effects of temperature or for independent effects of precipitation did not lead to improvements in the first-stage regressions, and often led to a decline in the combined explanatory power of the excluded instruments.

Table 1.2: 'First stage' and reduced form regressions

	'First Stage' Regressions				Reduced Form Regressions		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	OLS/FE	OLS/FE	OLS/FE	OLS/FE	OLS/FE	OLS/FE	SGMM
ln(wtem)	-0.338***	-0.469***	-0.468***	-0.526**	-0.234**	-0.293***	-0.276***
	(0.094)	(0.144)	(0.141)	(0.210)	(0.088)	(0.088)	(0.080)
$\ln(\text{wtem})_{t-1}$		0.354**	0.317*	0.403*		0.112	0.129*
		(0.165)	(0.170)	(0.218)		(0.074)	(0.076)
$\ln(\text{wtem})_{t-2}$			0.151	0.116		0.085	0.139
			(0.106)	(0.116)		(0.082)	(0.091)
$\ln(\text{wtem})_{t-3}$			-0.097	-0.090		-0.007	-0.008
			(0.104)	(0.127)		(0.062)	(0.059)
Country FE	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y
Region-Year FE	N	N	N	Y	N	N	N
Controls	N	N	N	N	N	N	N
F-Stat of ln(wtem)	13.055	6.313	3.301	1.841	7.006	3.379	3.954
p-value	0.001	0.003	0.016	0.132	0.010	0.015	0.006
$\sum$ ln (temp)	-0.338	-0.115	-0.096	-0.097	-0.234	-0.103	-0.016
p-value	0.001	0.166	0.265	0.412	0.010	0.402	0.332
Lags of Δ ln (Man. V.A.)	2	2	2	2	2	2	2
$\sum \Delta$ ln (Man. V.A.)	0.017	0.024	0.025	0.036	0.054	0.085	0.118
p-value	0.550	0.423	0.417	0.243	0.337	0.063	0.037
Countries	62	62	62	62	62	62	62
Avg. Obs. per Country	36.065	36.065	36.032	36.032	36.145	36.113	36.113
Long-run Multiplier					-0.247	-0.113	-0.018
p-value					0.011	0.402	0.331
Num. of GMM Instruments							53
Lags of GMM Instruments							2
AR(2) test (p-value)							0.457
Hansen test (p-value)							0.117

*** p<0.01, ** p<0.05, * p<0.1

Notes: The dependent variable in the "first-stage" regressions (columns 1-4) is growth in real value added in agriculture. The dependent variable in the reduced-form regressions (columns 5-7) is growth in real value added in manufacturing. *Ln*(wtem) indicates the log of population-weighted average temperature. All specifications include a set of year dummies and two lags of growth in manufacturing. Specification (4) includes a set of region-specific dummies, where the regions are Middle-East and North Africa; Sub-Saharan Africa; Latin America and the Caribbean; Asia and Pacific Islands. Standard errors robust to arbitrary forms of correlation within countries are in parentheses. Columns labeled "OLS/FE" indicate the fixed-effects estimator, while columns labeled "SGMM" indicate the Arellano-Bover-Bond system GMM estimator (see description in the text).

These results confirm the findings in Dell et al. (2012a) regarding the effects of average temperature on agricultural growth in poor countries.[12] They also resonate

[12]Dell et al. (2012a) define poor countries as those whose PPP-adjusted GDP per capita is below the sample median in the first year the country enters their dataset, which includes both developing and developed countries.

with the broader literature on the effects of temperature on crop yields, reviewed above.

Columns (6)-(8) show that higher-than-average temperature hurts growth in manufacturing. In fact, the reduced-form relationship between temperature and growth in manufacturing resembles the relationship between temperature and growth in agriculture, as indicated by the signs of the contemporaneous and lagged coefficients. This finding is reassuring, since reduced-form estimates are free of the bias inherent in instrumental variable estimates (Angrist and Pischke, 2008). More importantly, it suggests that short-run variation in growth in agriculture is driving the reduced-form effect of temperature on manufacturing.

1.4.2 Baseline Results

Table 1.3 presents different specifications of the empirical model in equation (2.2) with the log of average temperature as an instrument for growth in agriculture. Column (1) displays the results of estimating a just-identified version of the model — with no lags of growth in agriculture, and only contemporaneous temperature as an instrument. By having as many excluded instruments as endogenous variables, this specification is least likely to suffer from weak-instrument bias (Angrist and Pischke, 2008). It estimates a positive, large, and statistically significant effect of growth in agriculture on contemporaneous growth in manufacturing.

Column (2) adds one lag of temperature to the instrument set.[13] The estimate remains large, but about one and a half decimal point lower than in the just-identified model. An increase in growth in agriculture by one percentage point is now predicted to increase contemporaneous growth in manufacturing by 0.54 percentage points —

[13] I estimate the overidentified models by GMM, although the results change little if two-stage least squares are used instead.

over five times higher than its counterpart estimated by OLS (compare it with column 1 in table 1.1).

Column (4) adds two lags of growth in agriculture, with a total of three lags of temperature in the instrument set. The additional lags have positive coefficients, and these are also higher than their counterparts in the models estimated by OLS. Conditional on current agricultural growth, however, the effects of past agricultural growth are too imprecisely estimated to be deemed individually significant. This fact indicates that annual variation in temperature, with its strong mean-reverting character, is best suited for identifying short-run effects of agricultural growth. Seen from a different angle, the coefficients identified on the basis of short-run variation in temperature do not reflect longer-term changes to the economic landscape — such as technical change, or trade and macroeconomic policies — that could follow in the wake of persistent changes in growth in agriculture.

As a result, even though the implied long-run multipliers in the specifications with lagged agricultural growth are statistically significant, I adopt the short-run coefficients of the specifications without lags (such as that in column 2), as well as their associated long-run multipliers, as the baseline estimates. The addition of lags of agricultural growth hardly changes these contemporaneous coefficients.

Columns (3) and (5)-(7) address two potential shortcomings of the specifications just described. First, to address concerns with Nickell bias, columns (6) and (7) show the same specifications as those of columns (2) and (4), but now estimated using the Arellano-Bover-Bond procedure. As we can see, the estimated short-run effect of growth in agriculture is about a decimal point lower (but still significant). At the same time, growth in manufacturing exhibits more persistence, so differences in the long-run multipliers are small.

In turn, the specifications in columns (3) and (5) are estimated by the Limited Information Maximum Likelihood (LIML) method, to address concerns with weak

Table 1.3: Baseline estimates with temperature as instrument for agricultural growth.

	(1) GMM	(2) GMM	(3) LIML	(4) GMM	(5) LIML	(6) SGMM	(7) SGMM
Δ ln (Agr. V.A.)	0.684**	0.547***	0.559***	0.581***	0.581***	0.476**	0.455***
	(0.280)	(0.185)	(0.190)	(0.182)	(0.185)	(0.185)	(0.157)
Δ ln (Agr. V.A.)$_{t-1}$				0.157	0.157		0.201
				(0.193)	(0.200)		(0.191)
Δ ln (Agr. V.A.)$_{t-2}$				0.112	0.112		0.046
				(0.145)	(0.147)		(0.166)
Country FE	Y	Y	Y		Y	Y	Y
Year FE	Y	Y	Y		Y	Y	Y
Lags of Δ ln (Man. V.A.)	2	2	2	2	2	2	2
$\sum \Delta$ ln (Man. V.A.)	0.043	0.045	0.045	0.030	0.030	0.102	0.089
p-value	0.423	0.399	0.394	0.629	0.631	0.050	0.274
Long-run Multiplier	0.714	0.573	0.586	0.876	0.876	0.530	0.771
p-value	0.015	0.003	0.004	0.004	0.007	0.012	0.036
Lags of ln(temperature)	0	1	1	3	3	1	3
Anderson-Rubin Stat	7.127	14.457	14.457	14.060	14.060		
p-value	0.008	0.001	0.001	0.007	0.007		
Stock-Wright Stat	6.354	10.078	10.078	10.150	10.150		
p-value	0.012	0.006	0.006	0.038	0.038		
Kleibergen-Paap Stat.	13.062	6.316	6.316	2.388	2.388		
Cragg-Donald Stat	14.489	14.131	14.131	6.678	6.678		
10% Max Size Crit. Val.	16.380	19.930	8.680	n/a	n/a		
15% Max Size Crit. Val.	8.960	11.590	5.330	n/a	n/a		
Hansen test (p-value)		0.479	0.481	0.998	0.998	0.444	0.253
Num. of GMM Instruments						51	53
Lags of GMM Instruments						2	2
AR(2) test (p-value)						0.636	0.564
Countries	62	62	62	62	62	62	62
Avg. Obs. per Country	36.048	36.048	36.048	35.919	35.919	36.048	35.919

*** p<0.01, ** p<0.05, * p<0.1

Notes: The dependent variable is growth in real value added in the manufacturing sector. Standard errors robust to arbitrary forms of correlation within countries are in parentheses. Columns labeled 'GMM' indicate that the GMM method was used for estimating the models with more instruments than endogenous variables. Columns labeled 'LIML' indicate that the Limited Information Maximum Likelihood method was used instead. Columns labeled 'SGMM' indicate the use of the Arellano-Bover-Bond system GMM method (for a description, see the text). The Stock-Yogo critical values for maximal size distortion were computed for the Cragg-Donald F statistic, which assumes i.i.d. disturbances. They were reported only when available.

instrument bias. These estimates are close to those obtained in columns (2) and (4), providing clear evidence against bias. Simulations show that LIML brings significant improvements in median bias relative to standard standard methods in finite samples with multiple weak instruments. As instrument strength improves, the difference in

median estimates between LIML and standard methods declines, indicating a decline in median bias in the latter (Flores-Lagunes, 2007).

Formal tests of weak identification confirm these findings. These testing procedures, originated by Anderson and Rubin (1949), are based on the joint significance of the external instruments in reduced-form regressions like those of table 1.2.[14] Table 1.3 reports an Anderson-Rubin Wald statistic that is robust to autocorrelation and heteroskedasticity, as well as a closely related LM statistic proposed by Stock and Wright (2000). As we can see, both statistics lead us to reject the null hypothesis of weak identification in all specifications.

The LIML method also improves inference in the presence of weak instruments by reducing size distortions (Stock and Yogo, 2005). To illustrate this property, table 1.3 reports the Cragg-Donald Wald statistic, which is based on the joint significance of the excluded instruments in explaining the endogenous regressors. The computed values should be measured against the critical values obtained by Stock and Yogo (2005), which indicate cutoffs for maximum levels of size distortion. These critical values were reported only when available. Both the Cragg-Donald statistic and the critical values, however, assume i.i.d. disturbances.[15] A comparison of columns (3) and (2) reveals lower critical values for the model estimated by LIML, indicating that, given the strength of the instruments, LIML suffers less size distortion than the standard GMM estimator.

In sum, the instrumental variable estimates reveal a large and statistically significant short-run effect of growth in agriculture on growth in manufacturing. If we take

[14] If the exclusion restriction is valid, the reduced-form coefficients can be considered a function of both of the effect of growth in agriculture on growth in manufacturing (i.e. the coefficients of the structural equation of interest) and of the effect of temperature on growth in agriculture (i.e. the coefficients on the excluded instruments in the first-stage regression). A weak first-stage relation would thus lead to insignificant coefficients in the reduced-form regression (for more details, see Baum et al., 2007).

[15] I also report the closely related Kleibergen-Paap Wald statistic, which is robust to heteroskedasticity and autocorrelation, but without accompanying critical values.

the parsimonious LIML and system GMM estimates in columns (3) and (6) as the baseline, an increase in growth in agriculture by one percentage point is expected to raise contemporaneous growth in manufacturing by between 0.47 and 0.56 percentage points.

The calculated long-run multipliers are also statistically significant and of similar magnitude (0.53 and 0.58). They suggest that if the average country in the sample were to permanently increase the rate of growth in agriculture by 1.8 percentage points (reaching the same rate exhibited by China during the sample period), the predicted long-run increase in growth in manufacturing would range between 0.95 and 1 percentage point. Such a sustained effort to raise growth in agriculture would be a remarkable achievement, as the sample mean of growth in agriculture, as seen in section 1.3, is only 2.6%/yr. Even though the long-run multipliers should be interpreted with caution — as they were estimated on the basis of short-run variation in the instrument —, they suggest that the payoff of sustained increases in agricultural growth would be substantial.

1.5 Interactions and Robustness Checks

This section tests whether the results are robust to cross-country heterogeneity, non-macroeconomic effects of growth in agriculture, changes in the sample, and the influence of outliers. It also provides further discussion on the validity of the exclusion restriction in (1.4).

The sample used in this paper includes only developing countries, as opposed to the related studies of Dell et al. (2012a) and Shifa (2015). Yet growth in agriculture may affect the manufacturing sector differently depending on country characteristics such as the share of agriculture in GDP, or the degree of openness to trade. In table 1.4, I explore potential sources of heterogeneity in two ways.

First, I estimate the baseline specification (including only contemporaneous growth in agriculture) with a full set of year dummies interacted with quartile rank dummies. Each quartile rank dummy indicates whether, at the time it entered the sample, a country belonged to that quartile of the distribution of a given characteristic of interest. The characteristics include PPP-adjusted GDP per capita, the share of agriculture in GDP, the share of imports and exports in GDP, and the share of agricultural exports in GDP (for detailed sources and definitions, see table B.1 in Appendix B).

These year-rank interactions absorb variation across countries belonging to different quartiles; as a result, the coefficients are estimated only on the basis of variation within each quartile. In other words, only similar countries (in terms of initial conditions) provide a yardstick to evaluate the effect of agricultural growth in each country. Columns (1)-(4) show that little is changed by adding year-rank interactions to the baseline LIML specification.[16] The only noticeable change occurs when the characteristic of interest is the share of agricultural exports in GDP, leading to an increase in the point estimate to 0.62.

Second, I add the interaction between growth in agriculture and a dummy indicating whether, at the time it entered the sample, a country was above the median in the distribution of each of the characteristics above. Columns (5)-(8) show the results ('poor' indicates a below-median initial GDP per capita).[17] As we can see, the interaction terms are too imprecisely estimated to be statistically significant. Column (6) suggests a stronger effect of agricultural growth in countries with a higher share of agriculture in GDP. In turn, columns (7) and (8) suggest a weaker effect in countries that are more open, or more oriented towards primary exports. One could

[16]Due to the limited number of countries, it is not possible to repeat this exercise with the Arellano-Bover-Bond system GMM estimator, as the total number of instruments far exceeds the number of cross-sectional units (Roodman, 2009).

[17]To estimate these specifications, I used the fitted values of a first-stage regression as the instrument for growth in agriculture (for a discussion, see Wooldridge, 2010).

Table 1.4: Robustness checks and interaction effects

	Year-Quartile Rank Dummies							
	(1) gdp per cap.	(2) agr. share in gdp	(3) agr. exp. in gdp	(4) trade in gdp	(5) poor	(6) agr. share in gdp	(7) agr. exp. in gdp	(8) trade in gdp
Δ ln (Agr. V.A.)	0.554***	0.513***	0.625***	0.555***	0.543***	0.525***	0.611***	0.678***
	(0.185)	(0.183)	(0.201)	(0.171)	(0.173)	(0.183)	(0.232)	(0.254)
Interaction					0.025	0.291	-0.208	-0.249
					(0.230)	(0.337)	(0.236)	(0.234)
Country FE	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	N	N	N	N	Y	Y	Y	Y
Year-Rank FE	Y	Y	Y	Y	N	N	N	N
Lags of Δ ln (Man. V.A.)	2	2	2	2	2	2	2	2
$\sum \Delta$ ln (Man. V.A.)	0.042	0.054	0.051	0.046	0.045	0.047	0.047	0.041
p-value	0.397	0.193	0.344	0.342	0.396	0.384	0.378	0.445
Long-run Multiplier	0.578	0.542	0.659	0.582	0.569	0.551	0.641	0.707
p-value	0.003	0.005	0.002	0.001	0.002	0.005	0.009	0.007
Lags of ln(temperature)	1	1	1	1	1	1	1	1
Anderson-Rubin Stat	15.854	15.693	12.791	15.680	15.599	16.183	15.639	14.461
p-value	0	0	0.002	0	0	0	0	0.001
Stock-Wright Stat	10.281	10.136	10.253	11.300	10.509	12.474	10.752	10.113
p-value	0.006	0.006	0.006	0.004	0.005	0.002	0.005	0.006
Kleibergen-Paap Stat.	8.119	6.094	4.268	5.650	3.104	2.515	4.859	4.468
Cragg-Donald Stat	15.124	14.267	10.800	15.088	12.692	9.408	14.892	14.777
10% Max Size Crit. Val.	8.680	8.680	8.680	8.680	7.03	7.03	7.03	7.03
15% Max Size Crit. Val.	5.330	5.330	5.330	5.330	4.58	4.58	4.58	4.58
Countries	62	58	59	61	62	62	62	62
Avg. Obs. per Country	36.048	35.966	36.424	36.082	36.048	36.048	36.048	36.048

*** p<0.01, ** p<0.05, * p<0.1

Note: The dependent variable is growth in real value added in the manufacturing sector. All specifications were estimated by the Limited Information Maximum Likelihood method. Standard errors robust to arbitrary forms of correlation within countries are in parentheses. Columns (1)-(4) include a full set of interaction dummies between year and the rank of a country in the quartiles of each characteristic at the time the country enters the sample. The characteristics of interest are listed in the column headers (for detailed variable definitions, see the text and Appendix B). The variable 'interaction' in columns (5)-(8) denotes the interaction term between growth in agriculture and a dummy indicating whether a country lies above the overall median in the distribution of each characteristic at the time the country enters the sample ('poor' indicates whether a country lies below the overall median of GDP per capita). The Stock-Yogo critical values for maximal size distortion were computed for the Cragg-Donald F statistic, which assumes i.i.d. disturbances.

find justification for these differentials in the theoretical literature: as discussed in section 1.2, demand-side complementarity between agriculture and industry hinges on the response of intersectoral relative prices to increases in agricultural output. In small economies, greater openness to trade may link many domestic relative prices to their counterparts in world markets, thereby narrowing the scope for demand-side complementarity. But the available data warrants no firm inference in this respect.

Table 1.5 shows the remaining robustness checks, with LIML estimates in the top panel, and Arellano-Bover-Bond estimates in the second panel. Column (1) reproduces the baseline specification for ease of comparison.

I first examine two potential violations of the exclusion restriction. The first are the political effects of climate variation. An influential literature has shown that climate shocks increase the likelihood of civil unrest and regime changes, especially in least developed countries (Miguel et al., 2004; Hidalgo et al., 2010; Brückner and Ciccone, 2011). These forms of conflict emerge because climate shocks hurt crop yields and rural livelihoods, so they are not independent of agricultural growth. But the accompanying unrest may confound the more strictly macroeconomic effects that motivate this paper.

To address the problem, in column (2) I extend the baseline specification by adding up to two lags of an indicator of civil conflict of any type and extent; it is based on Marshall (2013), who codes the severity of episodes of civil violence, civil war, ethnic violence and ethnic war. The coefficients on the conflict dummies are negative and statistically significant, but column (2) shows that the coefficient on agricultural growth remains similar to the baseline levels.

The second potential violation is the effect of variation in temperature on energy markets: the same climate phenomena causing fluctuations in temperature may be causing fluctuations in precipitation. In countries that rely on hydropower production, higher temperature may hurt manufacturing growth by driving up energy prices, quite

apart from its effect on agriculture. In column (3), I control for the growth rate of national hydropower production, again without substantial changes to the coefficients of interest (see table B.1 for variable definitions).[18]

The specifications in columns (4) and (5), in turn, limit the variation in temperature used for identification, in an attempt to curb possible direct effects of large temperature swings on the manufacturing sector (see the discussion in section 1.4). The estimates in column (4) exclude countries with an interquartile range in average temperature above above the 90th percentile (about 1.06^{o}C). In turn, the estimates in column (5) exclude observations with average temperature above the 95th country-specific percentile, or bellow the 5th country-specific percentile. As we can see, with the exception of the LIML estimate in column (5), which is a decimal below the baseline level, the point estimates change little.

The specifications in columns (6) and (7) examine the sensitivity of the results to influential observations. The specification in column (6) excludes the observations whose residuals (obtained from the baseline specification) are in the top or bottom percentiles. In turn, the estimates in column (7) are obtained with a Winsorized (at 1%) dependent variable. As expected, these procedures reduce the influence of outliers and lead to an overall reduction of about a decimal point in the estimates. In the models estimated by LIML, however, the decline in the short-run coefficients is partly compensated by higher persistence of growth in manufacturing, leading to only modest changes in the long-run multipliers. The largest reduction occurred in the specification with excluded outliers estimated by the Arellano-Bover-Bond procedure, with the contemporaneous effect dropping to 0.28.

These results suggest that, to some extent, the baseline estimates are sensitive to influential observations, and columns (6) and (7) thus provide more conservative

[18]This conclusion holds if up to two lags of the level of hydropower production are used instead of its growth rate.

Table 1.5: Additional robustness checks

	(1) Baseline	(2) Conflict	(3) Hydropower Production	(4) Truncated Temp. IQR	(5) Truncated Outliers (temp.)	(6) Truncated Outliers (resid.)	(7) Winsorized Dep. Var.
	LIML Estimates						
Δ ln (Agr. V.A.)	0.559***	0.577***	0.551***	0.557***	0.459***	0.470***	0.486***
	(0.190)	(0.203)	(0.201)	(0.196)	(0.168)	(0.178)	(0.168)
Long-run Multiplier	0.586	0.609	0.577	0.568	0.499	0.542	0.534
p-value	0.004	0.005	0.006	0.005	0.005	0.008	0.004
Hansen test (p-value)	0.481	0.396	0.648	0.354	0.693	0.462	0.603
Countries	62	61	49	54	62	62	62
Avg. Obs. per Country	36.048	36	31.959	35.630	24.323	34.113	36.048
	Arellano-Bover-Bond SGMM Estimates						
Δ ln (Agr. V.A.)	0.476**	0.492**	0.540**	0.495**	0.433**	0.286**	0.384**
	(0.185)	(0.203)	(0.212)	(0.207)	(0.170)	(0.126)	(0.145)
Long-run Multiplier	0.530	0.558	0.622	0.542	0.487	0.347	0.443
p-value	0.012	0.017	0.010	0.020	0.012	0.036	0.012
AR(2) test (p-value)	0.636	0.679	0.440	0.658	0.305	0.216	0.878
Hansen test (p-value)	0.444	0.468	0.839	0.429	0.281	0.172	0.481
Countries	62	61	49	54	62	62	62
Avg. Obs. per Country	36.048	36	31.959	35.630	24.323	34.177	36.048

*** p<0.01, ** p<0.05, * p<0.1

Note: The dependent variable is growth in real value added in the manufacturing sector. The specifications in the top panel were estimated by the Limited Information Maximum Likelihood method using the within transformation. The specifications in the bottom panel were estimated by system GMM using the Arellano-Bover-Bond moment conditions. Standard errors robust to arbitrary forms of correlation within countries are in parentheses. All specifications include a full set of year dummies and use the contemporaneous plus one lag of temperature as instruments for growth in agriculture. Column (2) includes up to two lags of a dummy indicating the existence of civil conflict. Column (3) includes the growth rate of hydropower production (see the text and Appendix B for detailed variable definitions). Column (4) excludes countries with an interquartile range of average temperature above the 90th percentile (about 1.06^{o}C). Column (5) excludes observations with average temperature above the 95th country-specific percentile or bellow the 5th country-specific percentile. Column (6) drops the observations whose residuals (obtained from the baseline specification) are above the top or bellow the bottom percentiles. Column (7) uses a Winsorized (at 1%) dependent variable.

estimates of the average impact of growth in agriculture. In all cases, however, the estimates remained practically large and statistically significant.[19]

1.6 Potential Mechanisms

In section 1.2, I discussed several channels through which the agricultural sector could relieve macroeconomic constraints on industrial growth, namely saving, demand, foreign exchange, and fiscal constraints. In this section, I provide suggestive evidence on the impact of growth in agriculture — still instrumented by temperature — on proximate measures of these channels. I therefore replace other outcomes of interest for industrial growth in the empirical model in (2.2).

I estimate all specifications by system GMM using the Arellano-Bover-Bond moment conditions, including four lags of the dependent variable in the case of variables defined as ratios, and two lags in the case of variables defined as growth rates.[20] With one exception, I add no other controls, so as not to restrict the channels through which growth in agriculture can affect the outcome variables. [21] For detailed variable definitions, see table B.1 in Appendix B.

Table 1.6 summarizes the results. Column (1) shows that a one-off increase in agricultural growth leads to a decline in the terms of trade between agriculture and the total economy. As described in section 1.2, a reduction in the intersectoral terms

[19]The set of countries with at least one excluded observation in column (6) includes 25 countries, 15 of which are located in Sub-Saharan Africa. But no country has more than 3 excluded observations. It must be noted that, even though the results are sensitive to the excluded observations, no a priori reason exists to believe that the information these observations convey is less legitimate than that of the remaining ones.

[20]I also report a single-tailed test of the hypothesis that the sum of lagged coefficients is less than one, to address concerns with the stationarity of the variables in ratios.

[21]The exception is the model with the terms of trade between agriculture and the total economy as a dependent variable. That model controls for up to two lags of real GDP growth, so the counterfactual is characterized by a given rate of GDP growth. All else equal, higher growth in the non-agricultural sector would be expected to turn the terms of trade in favor of agriculture under imperfect tradability (see, e.g. Ros, 2001, chapter 3).

of trade indicates that higher growth in agriculture can serve as an autonomous source of demand for industrial goods (for example, by lowering the cost to workers of meeting their inelastic demand for food, and thus liberating income to be spent on industrial goods).

Columns (2) and (3) show that higher growth in agriculture raises the shares of gross capital formation and gross domestic saving in GDP. These results indicate that higher resource utilization in industry not only lead to higher output, but also induce firms to step up the rate of accumulation.

Column (4), in turn, shows that higher growth in agriculture raises the growth rate of real GDP per worker. These short-run effects are unlikely to reflect technical change, but rather a higher utilization of labor within sectors, on the one hand, and the reallocation of workers to sectors with higher value added per worker. This finding suggests that underemployment is pervasive in developing countries, as higher yields in agriculture are likely to raise labor requirements in a sector generally characterized by low value added per worker.

Columns (5) and (6) show that higher growth in agriculture raises the growth rate of agricultural exports, and lowers the share of food in total merchandise imports. Both effects indicate that agricultural development can raise a country's capacity to import industrial inputs, easing potential foreign exchange constraints on industrial accumulation. Column (7) also suggests that higher growth in agriculture raises the share of merchandise trade in GDP, but the effect is imprecisely estimated.

Finally, column (8) shows that higher growth in agriculture has no impact on the share of trade tax revenues in GDP, indicating that, as agricultural growth accelerates, trade tax revenues increase on a par with GDP. As described in section 1.2, indirect instruments such as trade tariffs and quotas have commonly allowed agriculture to ease fiscal constraints on the state.

In general, the coefficients suggest that large shocks to growth in agriculture are required to produce noticeable effects on most of these outcome variables. Large short-run shocks, however, are empirically plausible, given the within-country volatility exhibited by agricultural growth. For example, an increase in agricultural growth by one 'within' standard deviation (8.5 percentage points) is expected to contemporaneously lower the sector's domestic terms of trade by 5.8%, raise the share of gross capital formation in GDP by 1.82 percentage points, and lower the share of food in merchandise imports by one percentage point.

This section suggests that the theoretical literature has emphasized plausible channels of complementarity between agriculture and industry. At the same time, however, the regressions above do not isolate the contribution of each mechanism, nor do they identify the constraints on industrial growth experienced by specific country groups at specific times.[22] In particular, the estimates may also reflect short-run changes in other macroeconomic variables that are responsive to growth in agriculture. With these caveats in mind, it is reassuring to find that growth in agriculture improves indicators of different constraints that could bind industrial growth.

1.7 Conclusion

Development economists have long examined macroeconomic channels through which development in agriculture can support the expansion of high-productivity activities, particularly in manufacturing. The complementarity between the two sectors has also been a centerpiece of historical studies of industrialization. Efforts to identify causal effects using country-level datasets, on the other hand, are comparatively recent. This paper makes a contribution to this literature.

[22]Still, one may speculate that the short-run impact of growth in agriculture operates primarily through the demand channel, with higher industrial growth reflecting greater utilization of productive capacity. The reason is that foreign exchange constraints do not actuate at the level of individual firms and, along with fiscal constraints, they require a policy response before becoming effective.

Table 1.6: Impact of agricultural growth on potential mechanisms

	(1) agr/total t.o.t. (log)	(2) gross cap. form. (% gdp)	(3) gross saving (% gdp)	(4) labor prod. (growth)	(5) agr. exports (growth)	(6) food imports (% total)	(7) merch. trade (% gdp)	(8) trade tax rev. (% gdp)
Δ ln (Agr. V.A.)	-0.687**	0.222*	0.441***	0.407*	1.853**	-0.128*	0.474	-0.055
	(0.309)	(0.113)	(0.146)	(0.223)	(0.792)	(0.068)	(0.402)	(0.037)
Δ ln (Agr. V.A.)$_{t-1}$	-0.056	-0	-0.036	-0.104	1.642	-0.072	0.048	-0.032
	(0.439)	(0.099)	(0.222)	(0.185)	(1.037)	(0.088)	(0.430)	(0.033)
Δ ln (Agr. V.A.)$_{t-2}$	0.256	-0.094	0.141	0.021	0.359	0.010	0.252	-0.061
	(0.290)	(0.120)	(0.161)	(0.138)	(0.827)	(0.071)	(0.379)	(0.059)
Country FE	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Controls	Y	N	N	N	N	N	N	N
Lags of Dep. Var	4	4	4	2	2	4	4	4
$\sum$ Lagged Dep. Var.	0.953	0.928	0.950	0.222	-0.353	0.957	0.932	0.978
H$_o$: $\sum < 1$ (p-value)	0.996	0.886	0.990	1	1	0.806	0.981	0.736
Long-run Multiplier	-10.370	1.768	11.005	0.417	2.849	-4.442	11.393	-6.730
p-val	0.381	0.535	0.061	0.433	0.033	0.465	0.380	0.638
Num. of GMM Instruments	59	59	55	53	52	54	56	41
Lags of GMM Instruments	2	5	1	2	2	2	2	2
AR(2) test (p-value)	0.624	0.477	0.248	0.402	0.632	0.796	0.455	0.584
Hansen test (p-value)	0.137	0.126	0.145	0.563	0.224	0.072	0.849	0.304
Countries	62	62	62	57	59	62	57	54
Avg. Obs. per Country	36.516	37.129	37.452	34.947	38.220	23.806	37.719	23.574

*** p<0.01, ** p<0.05, * p<0.1

Note: The dependent variables are as follows. Column (1): the log of the terms of trade between agriculture and the total economy; column (2): gross capital formation as a share of GDP; column (3): gross saving as a share of GDP; column (4): annual growth rate of real GDP per person engaged; column (5): annual growth rate of real agricultural exports; column (6): food imports as a share of total merchandise imports; column (7): the sum of merchandise exports and imports as a share of GDP; column (8): trade taxes as a share of GDP (see Appendix B for detailed definitions). All specifications were estimated by system GMM according to the Arellano-Bover-Bond procedure with three lags of temperature as external instruments for agricultural growth. Standard errors robust to arbitrary forms of correlation within countries are in parentheses. Columns (1) includes two lags of GDP growth as controls.

Using population-weighted average temperature as an instrumental variable, my baseline estimates show that an increase in annual growth in agriculture by one percentage point is estimated to raise contemporaneous growth in manufacturing by between 0.47 and 0.56 percentage point in the baseline specifications, and between 0.28 and 0.47 percentage point in conservative specifications that limit influential observations.

Baseline estimates of the long-run effects of a permanent increase in agricultural growth are also large (between 0.53 and 0.58 percentage points) although, as argued above, the frequency of variation in the instrument is better suited to capture short-run effects.

As discussed in section 1.4, several studies have established the sensitivity of crop yields to temperature variation under the technical and geographical conditions of most developing countries. My empirical strategy therefore explores a source of variation in agricultural output that is similar to yield-increasing technical innovations, such as irrigation and water control, multiple cropping, high-yielding varieties, and fertilizers.

As such, this paper contributes to the debate on whether this type of technical change in agriculture promotes industrialization. As described in section 1.2, an influential strand of the literature has argued that yield-increasing innovations may hurt the industrial sector in small open economies by increasing labor absorption in agriculture and bidding up unit labor costs in industry (Matsuyama, 1992; Bustos et al., 2012). My findings suggest that the underlying assumptions required to generate these negative effects, such as full employment and perfect international tradability in both sectors, are unlikely to hold in most developing countries in the short to medium run.

On the contrary, my findings support the strands of the literature which emphasize agriculture's classic roles as a source of saving, foreign exchange, fiscal revenues, and a

home market for industry. Extensions of the basic empirical model indeed showed that growth in agriculture favorably affects indicators of these channels of complementarity .

The paper also suggests large benefits of reducing output volatility in agriculture — a characteristic of many developing countries, as seen in section 1.3. Technical progress can indeed be doubly beneficial: it can raise average growth in agriculture while reducing the sector's vulnerability to weather shocks.

In light of these findings, one can better appraise historical narratives that emphasize the contribution of yield-increasing innovations to the early industrialization of Japan and East Asia (see, e.g. Smith, 1959; Ishikawa, 1967; Amsden, 1979; Kay, 2001). Many of these innovations later spread to other countries in the region as part of the 'green revolution' and, according to some, they currently appear poised to transform agriculture in a set of developing countries in Africa (Larson et al., 2010). This paper suggests that the potential benefits of combining yield-increasing technical progress in agriculture with other industrial policies can be substantial (see Rao and Caballero, 1990, for further discussion of such policy combinations).

But two caveats related to the role of agriculture in long-term development processes are in order. First, as mentioned in section 1.2, once sustained industrial growth is underway, the emergence of labor shortages will eventually require that technical change in agriculture have a labor-saving bias. The effects of this pattern of technical change, however, are not analyzed in this paper.

Second, even though agricultural exports can relax foreign exchange constraints on industrial accumulation, primary export booms often stifle the long-run development of industry by causing real exchange overvaluation and the associated 'Dutch disease' (Krugman, 1987; Rajan and Subramanian, 2011). Moreover, excessive reliance on primary exports may render an economy vulnerable to external terms of trade shocks (Deaton, 1999; Bleaney and Greenaway, 2001). Again, complementary macroeco-

nomic and sectoral policies are needed to mitigate these problems and promote the diversification of exports.

This paper does not speak directly to these long-run issues. Despite its dynamic structure, the empirical model uses short-run variation in the instrument to estimate the coefficients. It therefore does not account for changes in the sectoral composition of employment, for the effects of long-lasting booms in primary exports, or for other long-run systemic changes that can shape the relationship between agriculture and industry.

Finally, the increases in agricultural yields used in the empirical model were generated by a bounty of nature. In reality, however, technical change is not free: it requires credit, research and extension services, and rural infrastructure. Due to well-known market failures, the state has played a crucial role in the provision of these inputs (de Janvry and Dethier, 1985). The state's fiscal resources have alternative uses in the non-agricultural sector which have to be weighed against the benefits of using them to promote agricultural development.

In other words, agricultural development is one ingredient among a set of policies to foster industrialization, and its role is likely to change as industrialization advances. A judicious examination of agricultural development as part of country-specific industrial policies is an exciting topic for further research.

CHAPTER 2

BIASED TECHNICAL CHANGE IN AGRICULTURE AND INDUSTRIAL GROWTH

2.1 Introduction

Recent empirical studies using data from developing countries have suggested that growth in agriculture can promote growth in urban activities, notably industry. A strand of this literature has used climate variables — such as temperature or rainfall — to identify this positive causal effect (see, e.g. Henderson et al., 2009; Shifa, 2015; de Souza, 2015). These studies confirm previous findings obtained from time series techniques (Kanwar, 2000; Chebbi and Lachaal, 2007; Tiffin and Irz, 2006). Together, these results lend support to the notion that technical progress in agriculture can contribute to the structural transformation of countries of incipient industrialization.

But in agriculture, perhaps more than anywhere else, technical progress has quite asymmetrical effects on the relative productivity of the sector's basic factors of production, land and labor. This strong factor-saving bias stems from the nature of most agricultural innovations. On the one hand, labor-saving innovations — often embodied in tractors — help to perform tasks that are labor-intensive, such as sowing, weeding, harvesting, and threshing. But they typically have little impact on land yields. On the other hand, land-saving innovations — such as multiple cropping, high-yielding varieties, irrigation, and fertilizers — raise land yields, but typically have little aggregate impact on labor productivity.

Too often, however, calls for agricultural modernization downplay the consequences of the different factor-saving biases of agricultural innovations (see, e.g. World

Bank, 2007). This omission is not inconsequential. Indeed, labor-saving innovations seldom raise output, but often reduce labor demand in agriculture (see, e.g. Binswanger, 1978, 1986; Agarwal, 1980b,a; Ali and Parikh, 1992, for empirical evidence). By contrast, land-saving innovations normally raise both output and labor demand, as evidenced by record of the 'green revolution' (Johnston and Cownie, 1969; Ruttan, 1977; Otsuka et al., 1994; Hossain et al., 2006). These asymmetrical effects bear witness to two technical features of agriculture in developing countries: the low elasticity of substitution between land and labor, and the primacy of the stock of effective land in determining the level of output (Ishikawa, 1967; Boyce, 1986b; Banerjee, 2010).

It is therefore encouraging that a recent contribution has examined how biased technical change in agriculture affects growth in the industrial sector. In a model embodying the two technical features above, Bustos et al. (2012) extended the influential analysis of Matsuyama (1992) to account for biased innovations. Like their predecessor, Bustos et al. (2012) assumed a small open economy characterized by perfect tradability in both sectors, competitive labor markets, and full employment. Not surprisingly, in this context land-saving innovations raise labor demand in agriculture and bid up industrial wages, reducing industrial employment and output. By contrast, labor-saving innovations lower labor demand in agriculture, and the competitive labor market ensures that the displaced workers are taken up by industry. Bustos et al. (2012) find empirical support for these predictions using municipal-level data for Brazil.

The theoretical and local-level empirical results of Bustos et al. (2012), however, are in conflict with the aforementioned studies that have used national-level measures of climate variables to identify exogenous increases in agricultural supply (in particular, Shifa, 2015; de Souza, 2015).[1] As it turns out, these studies have explored a

[1]See also Dell et al. (2012a) for reduced-form evidence of the macroeconomic impact of climate variables on growth.

source of variation in the data that resembles the medium-run effects of land-saving (and thus labor-absorbing) innovations. Indeed, controlled experiments and reduced-form estimates show that, under the technical and geographical conditions of most developing countries, annual fluctuations in climate variables affect growth in agricultural output precisely by affecting land yields (Adams et al., 1990; Mendelsohn et al., 2000; Parry et al., 2007; Dell et al., 2013). And contrary to what the model in Bustos et al. (2012) would predict, at the aggregate level higher land yields do increase industrial growth.

These results show that the two main assumptions required to generate a trade-off between employment creation in agriculture and industrial growth — namely, full employment and perfect international tradability in both sectors — are unlikely to hold in most developing countries. This paper presents an alternative medium-run growth model that eschews these two main assumptions. Instead of full employment and competitive labor markets, the model assumes the existence of hidden unemployment in rural areas; and instead of full international tradability, the model assumes that the domestic terms of trade between agriculture and industry respond to the level and composition of domestic demand.

The baseline specification assumes that accumulation in the industrial sector is constrained by aggregate demand. It provides the main result of the paper: land-saving technical change will promote industrial accumulation by raising the incomes of rural workers and enlarging the domestic market for manufactures. As a result of hidden unemployment, industrial growth accelerates even as agriculture absorbs more labor. By contrast, labor-saving innovations may aggravate the problem of hidden unemployment, bid down rural wages, and narrow the domestic market for industrial goods. This outcome is more likely if agriculture possesses a dual structure whereby a class of smallholding peasants and landless workers provides labor to a class of large landowners.

The baseline specification thus has affinities with post-Keynesian and Structuralist two-sector models in which industrial accumulation is constrained by aggregate demand (see, e.g. Taylor, 1982, 1983; Dutt, 1992; Rao, 1993; Skott, 1999; Rada, 2007). But the paper complements this literature in four main ways. First, it explicitly focuses on factor-saving biases in technical change in agriculture. Second, in addition to a demand-constrained growth regime, it also examines saving-constrained growth regimes in a unified framework. Not surprisingly, the main conclusions change according to the regime. Third, the model examines how agrarian class structure shapes the impact of technical change on rural incomes, and thus on aggregate demand for industry. And, fourth, unlike most of the literature, the model focuses on medium-run warranted growth paths where capacity utilization is at the level desired by firms. To do so, it extends the Harrodian model of Nakatani and Skott (2007) to a two-sector framework.

The focus on modeling medium-run growth accelerations is justified by the empirical studies that, as just described, used climate variables to identify the impact of growth in agriculture on industry. Indeed, despite estimating dynamic empirical models, these contributions used annual variation in climate variables. As a result, the estimated coefficients did not account for long-run systemic changes — such as the emergence of labor constraints — that can modify the relationship between technical change in agriculture and industrial growth. In accordance with this focus on explaining medium run growth accelerations, the model's long-run properties are kept at maximum simplicity (see sections 2.2.5 and 2.4 for further discussion).

The paper closes with an open-economy extension characterized by full tradability in both sectors — as in Matsuyama (1992) and Bustos et al. (2012) —, but without full employment. This extension shows that, even without demand-side complementarity, land-saving technical change in agriculture can still allow for greater accumulation in

industry by relaxing the foreign exchange constraints that often beset semi-industrial economies.

The paper thus provides plausible explanations for the empirical findings of complementarity between increases in agricultural land yields and growth accelerations in the industrial sector. Specifically, these empirical findings indicate that, in the average developing country, the industrial sector can benefit from a relaxation of demand constraints and foreign exchange constraints on accumulation. As classically proposed by Johnston and Mellor (1961), agriculture can play a role in relaxing these constraints.

In addition to illuminating empirical findings for large panels of countries, the paper also illuminates growth accelerations that followed in the wake of well-known spells of land-saving technical change in agriculture. For example, studies of the early industrialization of Japan point to the importance of irrigation and multiple cropping in mobilizing rural surplus labor, fostering a home market for manufactures, and generating a surplus liable to be appropriated by direct or indirect taxation (Smith, 1959; Ohkawa and Rosovsky, 1960; Ishikawa, 1967; Kay, 2001; Karshenas, 2004). In the post-war period, South Korea and Taiwan displayed a similar pattern of technical change and intersectoral resource flows (Lee, 1971; Amsden, 1979). After the spread of the green revolution in the 1960s and 1970s, land-saving innovations that raised output and created rural employment were also documented in areas of India, the Phillippines, and Thailand (Hossain, 1988; Bantilan and Deb, 2003; Estudillo and Otsuka, 2006). Recently, authors have suggested their potential for aiding development in Africa (Larson et al., 2010).

These experiences contrast with the post-war industrialization of some Latin American countries, such as Argentina and Brazil, where technical change in agriculture exhibited a marked labor-saving bias (De Janvry, 1978; Sanders and Ruttan, 1978; Santos, 1986). This bias aggravated the problem of underemployment in rural

and urban areas and narrowed the domestic market for manufactures. As a result, some have argued that it contributed to prematurely steering industrialization towards satisfying the demand of the upper brackets of income distribution (de Castro, 1975).

The remainder of this paper is organized as follows. Section 2.2 presents a medium-run model of warranted growth that encompasses both demand-constrained and saving-constrained regimes. The impacts of land-saving and labor-saving technical change in agriculture are examined in each regime. Section 2.3 presents the open economy version of the model mentioned above. Section 2.4 concludes the paper, and Appendices C and D present proofs of the main propositions and the short-run dynamics of the model.

2.2 A Medium Run Growth Model

2.2.1 Production and Wages

As discussed in section 2.1, agricultural technology is unique in that, first, there are scarce possibilities for substitution of labor for land and, second, packages of capital and intermediate inputs are typically adept at raising the productivity of only one of these primary factors. To capture these characteristics with maximum simplicity, a Leontieff function represents production in agriculture, and exogenous changes to the each production coefficient represent biased innovations.

$$A = Min(\sigma_a, q_a l_a) \tag{2.1}$$

where σ_a and q_a are exogenous output-land and output-labor coefficients. I normalize the total land stock and the total labor force to unity, so that l_a is the share of the labor force that is employed by agriculture on a full time basis.

The stock of effective land is the binding constraint on agricultural output:

$$A = \sigma_a \rightarrow l_a = \frac{\sigma_a}{q_a} \tag{2.2}$$

With hidden unemployment, l_a is in general less than the total rural labor force (i.e.: $l_a < 1 - l_m$, where l_m is the employment share of the industrial sector).

The product wage in agriculture (the real wage in agriculture in terms of the agricultural good) is proportional to the average output in the sector.

$$\omega_a = \beta \frac{\sigma_a}{1 - l_m} \tag{2.3}$$

where ω_a is the product wage in agriculture, $0 < l_m < 1$ is the share of workers employed in the industrial sector, and $0 < \beta < 1$. This specification embodies the notion that agriculture is a traditional sector: work and income sharing institutions permit workers not employed by industry to obtain a share in the sectoral product (Lewis, 1954; Cohen and Weitzman, 1975; Rao, 1994). In all scenarios discussed below, labor incomes in agriculture are high enough to allow for the consumption of industrial goods.

With this specification, it is easy to model how class structure shapes the impact of technical change on rural wages. Consider two polar scenarios. In the first, large surplus-extracting farms coexist with a smallholding subsector. This dual scenario is a stylized representation of many Latin American countries, especially during their post-war industrialization (see, e.g. García, 1966; Barraclough and Domike, 1966; Dillman, 1976). The two subsectors produce the same good, and the smallholders generate a marketed surplus beyond subsistence. The parameter σ_a thus represents a weighted average of the land productivities in each subsector. In turn, β is the share of labor incomes in total output — a distributional parameter which responds to technical change in the manner described momentarily. Rentiers save all of their income, and workers — both wage workers and smallholders — consume all of theirs. The propensity to save out of total rural income is thus $1 - \beta$.

In the second scenario, agriculture is comprised of a homogeneous class of owner-cultivators. It is a stylized representation of most East Asian countries, again especially during their post-war industrialization (Lee, 1971; Amsden, 1979; Lee, 1979). Now the product wage is simply the average income set aside for consumption; and, as in the dual case, 1-β can be regarded as the sector-wide propensity to save.

In both scenarios, the behavioral propensities to save are constant. As a result, technical change only affects β through income redistribution, and income redistribution is only possible in the dual scenario. Labor-saving and land-saving technical change will affect β in the manner specified below:

$$\begin{aligned} \frac{d\beta}{dq_a}\frac{q_a}{\beta} &= \begin{cases} -\phi & \text{(dual scenario)} \\ 0 & \text{(owner-cultivator scenario)} \end{cases} \\ \frac{d\beta}{d\sigma_a}\frac{\sigma_a}{\beta} &= \begin{cases} \theta & \text{(dual scenario)} \\ 0 & \text{(owner-cultivator scenario)} \end{cases} \end{aligned} \tag{2.4}$$

where θ and ϕ are the absolute values of the elasticities of β with respect to proportional changes in σ_a and q_a. They are functions of parameters and other variables of the model, but under general conditions, $\phi > 0$ and $\theta > 0$ (see below).

Purely labor-saving technical change leaves average incomes unaltered in the owner-cultivator scenario — the same number of workers will simply share a lower work requirement. By contrast, it increases the rentier share of total income in the dual scenario. The reason is that wages in surplus-extracting farms are tied to average earnings in the smallholdings. When surplus-extracting farms adopt labor-saving innovations, the newly redundant workers are pushed to the smallholdings, lowering average earnings therein and, therefore, the average product wage in agriculture. This

fall is captured by a decline in the share of total output appropriated by workers, β. Section C.1 in Appendix C formally illustrates this point.[2]

Land-saving technical change, by contrast, raises the total work requirement in both scenarios. For as long as underemployment exists (i.e. $l_a < 1 - l_m$), the additional requirement will be met from within agriculture. In the owner-cultivator scenario, workers enjoy a higher average income in terms of the agricultural good, but since the behavioral propensity to save is assumed constant, β does not change.

In the dual scenario, uniform land-saving technical change raises wages in two ways: first, by increasing output in the smallholding subsector and, second, by reducing the amount of underemployment.[3] The sector-wide wage share, β, rises if the proportional increase in average income in the smallholding subsector dominates the proportional increase in the sector-wide average income. This requirement will be met under general conditions: the surplus-extracting subsector only needs to be above a minimum size. Again, section C.1 in Appendix C formally illustrates these points.

A Leontieff function also describes production in the industrial sector, with the stock of utilized capital as the binding constraint on output.

$$M = \sigma_m K_m \rightarrow l_m = \frac{\sigma_m}{q_m} K_m \tag{2.5}$$

where M is industrial output, K_m is the (non-depreciating) industrial capital stock, $0 < l_m < 1$ is the share of the labor force employed in industry, σ_m is the output-capital ratio, and q_m is the output-labor ratio in industry.

[2] I assume that changes in the technical parameters of production in the dual scenario reflect uniform changes taking place in both subsectors. As discussed in section C.1 in Appendix C, the substantive results don't change if the aggregate changes are assumed to only reflect changes occurring in the surplus-extracting subsector.

[3] If land-saving technical change only takes place in the surplus-extracting subsector, only the second effect occurs.

The model yields a positive, but not necessarily constant wage premium between agriculture and industry. As long as wages in industry are not lower than consumption wages in agriculture, the participation constraint of industrial workers will be met:

$$w_m \geq \omega_a p_a \tag{2.6}$$

where w_m is the nominal wage in industry. Like rural rentiers, industrial capitalists save all of their income; by contrast, industrial workers consume all of theirs.

2.2.2 Wage Bargaining in Industry

Wage bargaining shapes the relationship between fluctuations in aggregate demand and changes in functional distribution in the industrial sector, giving rise to demand-constrained and saving-constrained growth regimes. As in the classic exposition of Marglin (1984), industrial workers bargain over nominal wages with a distributional norm as reference. Since labor productivity is a fixed parameter, it is a matter of indifference whether we express this distributional norm as a reference wage share or as a reference real product wage.

Unlike in Marglin (1984), however, bargaining is decentralized. In other words, workers expect to achieve a target product wage, but the actual product wage will also depend on the realized price level of the manufactured good, known only *ex post*. Therefore, the best workers can do is factor their expectations into their nominal demands. These assumptions imply the following expression for the rate of growth of nominal wages:

$$\hat{w}_m = B\left(\frac{w_m}{p_m}\right)^{-1}\left[\left(\frac{w_m}{p_m}\right)^{*} - \frac{w_m}{p_m}\right] + \hat{p}_m^e \tag{2.7}$$

where $B > 0$ is a constant, $\left({}^{w_m}/_{p_m}\right)^{*}$ is the reference product wage, $\hat{w}_m$ is the rate of growth of the nominal industrial wage, and $\hat{p}_m^e$ is the expected rate of inflation

of the industrial price. Subtracting the actual rate of industrial price inflation ($\hat{p}_m$) from both sides gives:

$$\widehat{\frac{w_m}{p_m}} = B\left[\left(\frac{w_m}{p_m}\right)^* - \frac{w_m}{p_m}\right] + \frac{w_m}{p_m}(\hat{p^e}_m - \hat{p}_m) \tag{2.8}$$

With constant labor productivity, a stationary distribution of income in the industrial sector requires a stationary product wage. Imposing $\widehat{\frac{w_m}{p_m}} = 0$ above and solving for the rate of price inflation gives

$$\hat{p}_m = \hat{p^e}_m - B + B\left[\frac{(1-\pi^*)}{(1-\pi)}\right] \tag{2.9}$$

where π is the industrial profit share, which is uniquely related to the product wage through ${}^{w_m}/_{p_m} = (1-\pi)q_m$.

For a given rate of expected inflation, equation (2.9) gives a schedule of actual rates of inflation and actual profit shares along which the real wage is stationary. I call it the wage bargaining equilibrium (WBE) schedule.

If the actual profit share exceeds the norm, wage bargaining equilibrium requires that workers fail to fully anticipate the rate of price inflation (i..e $\hat{p}_m > \hat{p^e}_m$). Changes in unanticipated inflation are therefore the mechanism through which changes in the industrial profit share can occur.

Seen from a different angle, a macroeconomic equilibrium requiring $\pi > \pi^*$ can only be sustained if inflation expectations are repeatedly frustrated. But if inflation exceeds expectations period after period, shouldn't workers update their nominal demands? A way out of this conundrum was classically proposed by Rowthorn (1977): workers are unlikely to fully incorporate their expectations into the bargaining process unless actual inflation is high.

Thus, if prices are growing slowly, workers find the costs of acting upon their expectations — e.g.: collective action problems, contentious negotiations with management— too large relative to the benefits. In Rowthorn's terminology, low inflation may be

expected (correctly held as a belief), but not anticipated (incorporated into the bargaining process).

If prices are rising fast, however, the cost of not acting upon expectations is too high. Workers will push harder to incorporate expectations into the bargaining process, for example by requiring shorter contracts or provisions for wage indexation. In light of the experience of advanced economies in the 1970s, Rowthorn (1977) posited that the transition to this behavior is likely to happen quickly as inflation exceeds a threshold beyond which it is deemed to be high.

To introduce Rowthorn's ideas into the bargaining framework above, re-write the WBE schedule (equation 2.9) as

$$\widehat{\frac{w_m}{p_m}} = 0 \Leftrightarrow \begin{cases} \hat{p}_m = \hat{p^e}_m - B + B\left[\frac{(1-\pi^*)}{(1-\pi)}\right] & \text{, if } \hat{p}_m < \hat{p^*}_m \\ \hat{p}_m = \hat{p^e}_m & \text{, if } \hat{p}_m \geq \hat{p^*}_m \end{cases} \tag{2.10}$$

The WBE schedule can be depicted in the $(\hat{p}_m, \pi)$ space as a discontinuous function with a threshold at $\hat{p^*}_m$. For a given rate of anticipated inflation $(\hat{p}^e_m)$, actual inflation can act as a redistributive mechanism, being positively associated with a higher profit share in industry. But only if it remains below the threshold $\hat{p^*}_m$. Beyond that point, inflation is fully anticipated in bargaining, losing its ability to redistribute income — and the profit share is pinned down at π^*.

2.2.3 Warranted Growth

Industrial firms operate in imperfect competition and make production decisions on the basis of conjectured individual demand curves, which may or may not materialize. They regard excess capacity as instrumental to their profit-maximizing strategies, as it grants them flexibility to respond to short-term demand fluctuations when expanding output is costly and time-consuming.

I assume that firms have a well-defined desired rate of capacity utilization. Too little utilized capacity gives ample flexibility to respond to unforeseen demand fluctuations, but at the cost of unduly depressing the output-capital ratio and, all else equal, the profit rate. By contrast, too much utilized capacity renders firms unable to adjust output quickly enough to attain their preferred levels of production.

To be sure, firms may adjust their desired rate of utilization in the face of prolonged periods during which they are unable to attain it. But as argued by Harrod (1939), it makes most behavioral sense for individual firms to adjust their rate of accumulation in order to attain the desired rate of utilization (see also Skott, 2012). Sustained departures of actual utilization from the target rate would thus lead to a strong cumulative response of investment decisions, so that the long-run sensitivity of utilization to variations in aggregate demand would be low. Little generality is lost by approximating this stable long-run rate of utilization by an exogenous desired rate.

As discussed in section 2.1, the paper focuses on expectations-consistent — or 'warranted' — growth paths along which actual utilization is equal to desired utilization. Of course, at any point in time the two may differ, and Appendix D examines the short-run dynamics through which equality can be restored.

The notion of warranted growth implies equality between the rates of capital accumulation ($\hat{K}_m$) and output growth ($\hat{M}$). Thus:

$$\hat{K}_m = \hat{M} = g(\pi, \hat{p}_m), \quad g_1 > 0, g_2 < 0 \tag{2.11}$$

The output growth function $g(.)$ embodies firms' decisions in the face of short-run production rigidities. As in Skott (1989) and Nakatani and Skott (2007), industrial output is a state variable with a predetermined level at any point in time. Instead of instantaneously choosing a level of output, firms rather choose the growth rate of output.

The profit share — which at any point in time is uniquely related to the profit rate — signals the benefits of expanding output. But, as mentioned above, doing so is not costless. In particular, the cost of adjusting to changes in output is convex — beyond a point, it becomes progressively difficult to expand or contract production. As a result, the output growth function is non-linear in the profit share, with a high sensitivity at intermediate values, low sensitivity at extreme values, and upper and lower bounds (for a thorough discussion of the output growth function, see Skott, 1989, and also Appendix D).

Inflation is also likely to shape firms' output growth decisions independently from its redistributive role. At low rates of inflation, this influence is likely to be low. But high rates of inflation may reduce the confidence with which firms hold beliefs about relative prices and income distribution, and the general deterioration in the business climate may stifle capitalist animal spirits. More importantly, high rates of inflation are likely to trigger contractionary policy responses which themselves dampen accumulation. The growth function in (2.11) captures these possibilities in stylized fashion by including inflation as an argument alongside the profit share.[4] As discussed below, the feedback from inflation to growth plays no important role in the demand-constrained regime, but it is important for allowing for the possibility of a saving-constrained regime in a context of independent investment decisions.

Along the warranted growth path, goods market equilibrium is ensured by

[4]The use of inflation as an argument of the accumulation function captures the direct and policy-induced effects mentioned above with maximum simplicity. The disadvantage of this specification, however, is that it includes both a jump variable (the profit share) and a component of its rate of change (the rate of change in the industrial price) as arguments of the accumulation function. A possible interpretation is that firms only take into account the equilibrium rate of inflation that emerges from the model, thus ignoring the fleeting spike in inflation that comes from assuming that the profit share as capable of adjusting instantaneously — a modeling device to capture relative adjustment speeds that has no counterpart in the real world. For further elaboration of the short-run dynamics of the model, see Appendix D.

$$\sigma_a = f(\omega_a, p)(1 - l_m) + f\left(\frac{w_m}{p_m}\frac{1}{p}, p\right) l_m \tag{2.12}$$

and

$$\sigma^d \pi + \frac{1}{K_m}(1 - \beta)\sigma_a p = g(\pi, \hat{p}_m) \tag{2.13}$$

where $f(.)$ is the per-worker demand for agricultural goods, with $f_1 > 0$ and $f_2 < 0$. In turn, $p = {}^{p_a}/_{p_m}$ is the relative price of the agricultural good, and σ^d is the output-capital ratio desired by firms.

Equation (2.12) is the equilibrium condition for the agricultural market, while equation (2.13) is the economy-wide saving-investment balance. As long as (2.12) holds, equation (2.13) implies equilibrium in the market for industrial goods.

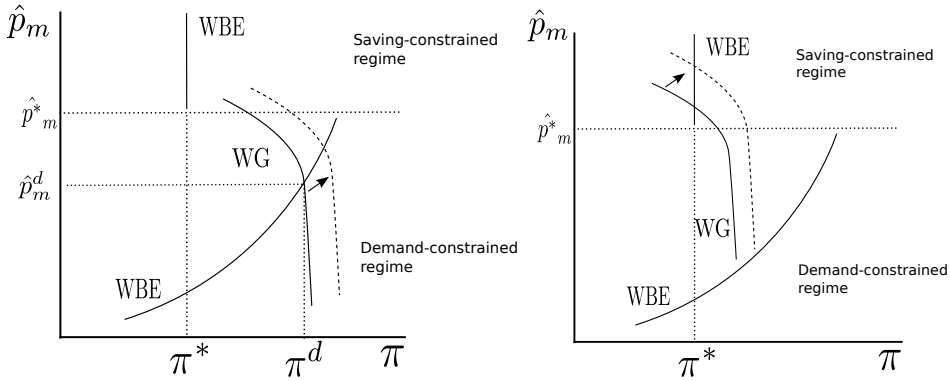
These two equilibrium conditions jointly determine the intersectoral terms of trade (p), and they give rise to a schedule in the $(\pi, \hat{p}_m)$ space along which market equilibrium is attained in both sectors. The associated slope is

$$\frac{d\hat{p}_m}{d\pi} = \frac{\sigma_m^d + \frac{1}{K_m}(1 - \beta)\sigma_a \frac{dp}{d\pi} - g_\pi}{g_{\hat{p}_m}} \tag{2.14}$$

The numerator in the expression above is the effect of an increase in the profit share on saving minus its effect on output growth. As shown in Appendix D, it has to be positive for the warranted growth path to be stable. Given the aforementioned non-linearity of the growth function in the (π, g) space, multiple equilibria are a possibility, with stability being attained where the response of output growth to changes in the profit share is relatively low relative to the response of saving (see Nakatani and Skott, 2007, and Appendix D). This stability condition is a correlate of the assertion that saving reacts more strongly to changes in the profit share than investment, known as Robinsonian stability in neo-Keynesian growth models (Robinson, 1962; Marglin and Bhaduri, 1990). I assume throughout that it holds.

Given that $g_{\hat{p}_m} < 0$, under stability the warranted growth schedule is downward-sloping in the $(\pi, \hat{p}_m)$ space, as shown by the WG schedule in figure 2.1. It is almost vertical at low levels of inflation, since firms' accumulation decisions are insensitive to changes in inflation when the level of inflation in low. Figure 2.1 also plots the discontinuous wage bargaining equilibrium schedule (from equation 2.10 above).

Figure 2.1: Growth regimes



(a) A demand-constrained regime

(b) A saving-constrained regime

Notes: The panels show the Wage Bargaining Equilibrium (WBE) and Warranted Growth (WG) schedules. Higher aggregate demand for industrial goods shifts the WG schedule to the right. In panel (a), market equilibrium is restored at a higher profit share and rate of accumulation in the industrial sector. Growth in this regime is therefore constrained by aggregate demand. In panel (b), the profit share is unresponsive to aggregate demand, since inflation fails to elicit higher saving by redistributing income. As a result, market equilibrium is restored at the conventional profit share and at higher inflation; higher demand thus fails to elicit a higher rate of accumulation.

The figure encapsulates the two basic growth regimes of the model. Higher aggregate demand for industrial goods — i.e. an *ex ante* shortfall of saving with respect to investment — will shift the WG schedule to the right. For any given rate of inflation, a higher profit share will be required to restore saving-investment balance and equilibrium in the market for industrial goods. This forced saving mechanism will operate as long as inflation remains below the threshold $\hat{p}^*_m$, so that it can effect the required redistribution of income from industrial workers to capitalists. This case is depicted in panel (a): an increase in aggregate demand for industrial goods will lead both to a higher profit share, which increases accumulation, and to a higher rate of inflation, which reduces accumulation. From (2.11), the net effect will be positive if

$$g_\pi > -g_{\hat{p}_m} \frac{d\hat{p}_m}{d\pi} \tag{2.15}$$

This condition is especially plausible in the demand-constrained regime, in which the sensitivity of growth to inflation, as well as inflation itself, are likely to be low. Moreover, this condition is required for the stability of the warranted growth path under both growth regimes (see Appendix D). I assume throughout that it holds. As a result, any equilibrium featuring a higher profit share will also feature higher accumulation in industry. Panel (a) thus shows a demand-constrained regime where industrial accumulation rises with aggregate demand for industrial goods.

If inflation is above the $\hat{p}_m^*$ threshold, however, it will be fully anticipated in wage bargaining, and the profit share will become unresponsive to increases in aggregate demand for industrial goods. In particular, increases in aggregate demand resulting from technical change in agriculture will only raise inflation without raising the profit share. As a result, they will hurt industrial accumulation. In this saving-constrained regime (illustrated in panel b), aggregate demand fails to increase accumulation because it cannot endogenously elicit higher saving.

The empirical results described in the introduction suggest that, in developing countries, technical change in agriculture is an important source of fluctuations in aggregate demand for industrial goods. The next section examines the macroeconomic mechanisms behind these fluctuations.

2.2.4 The Effects of Technical Change in Agriculture on Industrial Accumulation

In this section, I examine the effects of land-saving and labor-saving innovations on aggregate demand for industrial goods. Using the analysis of the previous section, I then show how these demand fluctuations affect capital accumulation under each of the two growth regimes.

I assume throughout that the warranted growth equilibrium is stable (see Appendix D). Under these conditions, equation (2.13) shows that technical change in agriculture will generate *ex ante* excess demand for industrial goods if it lowers the term $(1-\beta)\sigma_a p$, which is the value of agricultural saving in terms of the industrial good.

With regard to land-saving technical change, the following proposition can be established:

Proposition 2.2.1. *Land-saving technical change in agriculture (an increase in σ_a) will raise domestic demand for industrial goods if*

$$\begin{aligned} &\eta < 1-\epsilon && \textit{(owner-cultivator case)} \\ &\eta < \frac{1}{Z}\left\{1-\epsilon\left[\frac{1-(1+\theta)\beta}{1-\beta}\right]\right\} && \textit{(dual case)} \end{aligned} \tag{2.16}$$

where

$$Z = \frac{1-\beta+\theta(\alpha-\beta)}{1-\beta} < 1$$

and

$$0 < \alpha = \frac{f(\omega_a, p)(1-l_m)}{\sigma_a} < 1$$

In the expressions above, $\eta > 0$ and $\epsilon > 0$ are the income and price elasticities of the demand for agricultural goods. For simplicity, I assume that both elasticities are constant regardless of the level and composition of consumption. As before, $\Theta > 0$ is the elasticity of the distributional parameter β with respect to an increase in σ_a in the dual scenario. Finally, $0 < \alpha < 1$ is the share of agricultural workers in the total consumption of the agricultural good.

The assumption that labor incomes in agriculture are high enough to allow for the consumption of industrial goods ensures that $\alpha < \beta$ and, therefore, $Z < 1$ (reasonable parameter values also ensure that $Z > 0$).[5]

Proof. See Appendix C. □

Engel's law — the widely documented fact that the share of agricultural goods in total consumption declines with the level of income — implies a value of η below one. Since demand for food is likely to be price-inelastic (i.e. with a low ϵ), plausible Engel effects are strong enough to enforce the inequalities above.

The case of owner-cultivator agriculture provides the clearest intuition for these results. Land-saving technical change increases agricultural output and, for a given β, the value of agricultural saving in terms of the agricultural good. Agricultural saving in terms of the industrial good, however, will fall if the decline in agriculture's terms of trade is large enough. Engel effects ensure that this is the case.

In the dual scenario, this basic result is enhanced by the redistribution of rural income from landlords to workers (i.e. if $\Theta > 0$), as workers have a higher propensity to consume.

With regard to labor-saving technical change in agriculture, the following proposition can be established:

Proposition 2.2.2. *Labor-saving technical change in agriculture (an increase in q_a) will lower domestic demand for industrial goods in the dual case as long as rural consumption of industrial goods is positive (i.e. $\alpha < \beta$), and will have no effect in the owner-cultivator case.*

---

[5]The assumption that rural workers consume industrial goods implies that $f(\omega_a, p) < \omega_a$. Using the fact that $\omega_a = {}^{\beta\sigma_a}/_{(1-l_m)}$, it follows that the share of rural workers in total consumption of agricultural goods is lower than the wage share in the agricultural sector:

$$\frac{1}{\sigma_a} f(\omega_a, p)(1 - l_m) = \alpha < \beta$$

Proof. See Appendix C. □

Given the stylized assumptions about technology in agriculture, purely labor-saving technical change will have no effect on agricultural output. In the owner-cultivator case, moreover, it will have no effect on average incomes and saving behavior — it only changes the allocation of labor. As a result, no changes in rural demand for either good will ensue.

In the dual case, by contrast, labor-saving technical change in the surplus-extracting sector forces a reallocation of workers from the surplus-extracting to the smallholding subsector, depressing average incomes therein and lowering the overall agricultural wage share, β. The decline in β lowers the sector's propensity to consume and places a drag on aggregate demand for industrial goods. At the same time, however, lower rural demand for agricultural goods turns the terms of trade in favor of the industrial sector, lowering the cost to urban workers of meeting their income-inelastic demand for food. The higher real income is more than proportionately spent on the industrial good, providing partial compensation for lower rural demand. As shown in Appendix C, however, as long as rural consumption of industrial goods is positive (i.e. $\alpha < \beta$), the contractionary effects of the redistribution to the rentier class will prevail, and total demand for industrial goods will fall.

In light of the warranted growth regimes described in section 2.2.3, a strong labor-saving bias in agricultural technical change is likely to hurt industrial profitability and accumulation in a demand-constrained regime. Its effect could be illustrated by a downward shift of the WG schedule in Figure 2.1.

By contrast, a land-saving bias will expand the domestic market for industrial goods and lead to higher profitability and accumulation. Its effect could be illustrated by an upward shift of the WG schedule in Figure 2.1. Seen from a different angle, as long as hidden unemployment exists, land augmentation can allow agriculture to

fulfill a dual role as a medium-run outlet for surplus labor and as a source of expansion of the domestic market for industry.

These effects, however, require that income distribution in the industrial sector respond endogenously to aggregate demand. If the industrial sector is characterized by real wage resistance, demand-side complementarity ceases to exist even in a closed economy. Now a land-saving bias in agriculture will exert upward pressure on the industrial profit share and cause inflation to accelerate, hurting accumulation in order to reconcile higher consumption demand with an unyielding distributional norm. By contrast, a strong enough labor-saving bias in agriculture will reduce inflation and allow for higher accumulation in industry, at the cost of a temporary rise in rural underemployment.

Not surprisingly, the results depend heavily on the growth regime that characterizes the industrial sector, although the empirical results mentioned in the Introduction suggest that a demand-constrained regime is the typical scenario among developing countries in the medium run.

2.2.5 The Model in the Long Run

As the capital stock in the industrial sector expands, new workers are drawn out of rural areas and into the urban workforce. Demand for food will thus rise for two reasons: first, the workers recently employed by industry will start earning the urban wage premium; and, second, rural product wages rise as the degree of rural underemployment is reduced.

Given the model's central concern with modeling medium-run growth accelerations, the long-run scenario is kept at maximum simplicity by assuming that all parameters are constant. In this case, the additional demand for food will turn the terms of trade against industry and reduce aggregate demand for industrial goods.[6]

[6]Differentiation of equation (2.12) yields:

The economy will eventually transition to a demand-constrained regime and, from that point onwards, growth will decline as the economy transitions to a stationary state.

Assuming a demand-constrained regime with hidden unemployment is maintained throughout, one-off land-saving innovations will lead to temporary growth accelerations and the attainment of a higher capital stock in the stationary state.

2.3 Land-Saving Technical Change in a Small Open Economy

As discussed in the Introduction, some authors have challenged results like the above on the grounds that they don't carry over to small open economies with full tradability in both the industrial and the agricultural sectors (Matsuyama, 1992). Indeed, full tradability in a small open economy fixes the intersectoral terms of trade at the level of world prices, thus preventing changes in the level and composition of domestic demand from translating into changes in industrial profitability and accumulation.

The clearest challenge comes from Bustos et al. (2012), who like the present paper allow for biased technical change in agriculture. They assume factor substitutability in industry and a competitive intersectoral labor market leading to full employment. Under these conditions, land-saving technical change induces workers to relocate to agriculture at the expense of industrial employment and output. By contrast, labor-saving innovations induce workers to leave agriculture, and the competitive labor market ensures that they are taken up by industry.

$$\frac{dp}{dl_m} = \left[\frac{f^M - (1-\eta)f^A}{\epsilon\sigma_a + \eta f^M l_m}\right] p > 0$$

where f^M and f^A denote the per-worker demand for agricultural goods in the agricultural and the industrial sectors, respectively. Since $\eta > 0$, the expression is positive even if the urban wage premium is zero. From equation (2.13), it can be seen that an increase in l_m will increase the value of rural saving in terms of the industrial good and, therefore, reduce aggregate demand for industry.

As discussed in the Introduction, the present paper eschews the full employment assumption. But doing so is not sufficient to guarantee demand-side complementarity: as seen above, it also requires endogenous movements in the terms of trade. It is unclear that perfect tradability in both sectors is a realistic assumption, as Matsuyama (1992) himself admits. Still, given the influence of this assumption in the recent literature, an interesting question emerges: is there ever a case for land-saving technical change in a small open economy where the two sectors are fully tradable?

The short answer is yes, but only if the economy faces a binding balance-of-payments constraint on industrial accumulation. By only considering final demand in a Ricardo-Viner model of trade, the model in Matsuyama (1992) implies that trade at world prices remains balanced despite the fact that a reallocation of labor to industry may cause exports to contract. In semi-industrialized developing countries, however, the net foreign exchange requirements of the industrial sector may grow as the sector expands, due to the need to import intermediate and capital goods. Industrial accumulation may thus be constrained by insufficient foreign exchange earnings if the economy's ability to run persistent current account deficits is limited. In this section, I adapt the framework used so far to analyze a small open economy with surplus labor and independent investment decisions, but possibly beset by a binding balance of payments constraint on industrial accumulation.

The literature on 'gap' models provides a useful entry point. These models identify the main equality constraints that have to be satisfied as accounting identities in equilibrium. The literature's central contribution is the notion that one of these constraints will determine the feasible level of investment. The difference between this binding *ex ante* constraint and its less stringent counterparts is called a 'gap'. Since all equality constraints have to be satisfied *ex post*, the literature has posited a range of mechanisms through which all gaps are eventually eliminated (see, e.g. Chenery and Bruno, 1962; Bacha, 1990; Taylor, 1994). I examine the interaction between two

macroeconomic equality constraints: the aggregate goods market equilibrium and the balance of payments identity.

For simplicity, consider only the case of an endogenous premium between urban and rural wages (which corresponded to the demand-constrained growth regime above). The original model is modified in the following ways. First, both sectors now produce tradable goods with exogenous world prices, and no trade barriers exist. These assumptions fix the intersectoral terms of trade:

$$p = \bar{p} = \frac{p_a^*}{p_m^*} \tag{2.17}$$

where p_a^* and p_m^* are the exogenous world prices of the agricultural and the industrial goods.

Second, since industrial firms are now price-takers, they choose to work with full capacity utilization (the output-capital ratio is now just a technical coefficient). Third, the industrial good is an 'importable' good (i.e. tradable and typically imported), and the agricultural good is an 'exportable' good (tradable and typically exported). This assumption is meaningful for a number of semi-industrial countries where agricultural goods still make up the bulk of export receipts.

Fourth, the capital stock in industry (K_m) is a composite of the industrial good that is domestically produced (K_d) and of an investment good that can only be imported (K_i). These goods are utilized in fixed proportions, with $0 < m < 1$ denoting the share of the imported investment good. The value of the capital stock in domestic currency is given by equation (2.18) below, where e is the nominal exchange rate.

$$p_k K_m = p_m K_d + e p_k^* K_i \tag{2.18}$$

For maximum simplicity, I follow Taylor (1989) and assume that $p_k^* = p_m^*$, which implies that $p_m = p_k$. Doing so allows us to treat the industrial capital stock as if it

were homogeneous. In other words, the economy's imports are comprised two goods: the manufactured good that is also domestically-produced (it can be used either for consumption or investment), and the complementary capital good, which can only be used for investment. The economy's exports, in turn, are equal to the difference between domestic output and domestic consumption of the agricultural good.

Since the focus is on the contribution of technical change in agriculture to relaxing external constraints, I will not examine exchange rate movements as an instrument to reconcile accumulation targets with external balance. This assumption does not deny the usefulness of this instrument, but I note that, in general, endogenous exchange rate variation is not a substitute for contractionary policies in the face of external imbalances (see Chinn and Wei, 2013, for empirical evidence). This section suggests that technical change in agriculture can reduce the need for such contractionary policies.

Now the market equilibrium conditions are:

$$\sigma_a = f(\omega_a, p)(1 - l_m) + f\left(\frac{w_m}{p_m}\frac{1}{p}, p\right) l_m + X_a \tag{2.19}$$

and

$$\sigma_m K_m = [\omega_a - f(\omega_a, p)]\, p(1-l_m) + \left[\frac{w_m}{p_m} - pf\left(\frac{w_m}{p_m}\frac{1}{p}, p\right)\right] l_m + (1-m)I_m - M_m \tag{2.20}$$

where X_a denotes agricultural exports, M_m denotes imports of the industrial good that is also produced domestically, and I_m denotes industrial investment.

To derive the balance of payments identity, let m_k denote the imports of the capital good as a fraction of the industrial capital stock. Using the fact that $m_k = {}^{(mI_m)}/_{K_m} = mg$, the balance of payments identity is:

$$g = \frac{1}{m}(\kappa + px_a - m_m). \tag{2.21}$$

where x_a denotes agricultural exports, m_m denotes imports of the industrial good that is also produced domestically, and κ denotes net capital inflows — all expressed as a ratio of the industrial capital stock.

To analyze the contribution of agriculture to relieving a foreign exchange constraint on industrial accumulation, it is useful to work with separate functions for saving and investment. The saving-determined rate of growth of the capital stock is given by:

$$g^s = \sigma\pi + \frac{1}{K_m}(1-\beta)\sigma_a p + \kappa \tag{2.22}$$

The independent investment function, in turn, responds to the same determinants as before: profitability and inflation. But to show how a foreign exchange constraint can emerge and be corrected, assume that the investment function also responds positively to a shift variable z, which captures a policy-determined autonomous component of investment.

$$g^i = g^i(\pi, \hat{p}_m, z), \quad g_1 > 0, g_2 < 0, g_3 > 0 \tag{2.23}$$

To analyze the model graphically, it is easiest to to use the balance of payments identity in (2.21), and the saving and investment functions in (2.22) and (2.23). Equilibrium in the market for the agricultural good determines the level of agricultural exports (using equation 2.19). Given the so-determined level of agricultural exports, the joint satisfaction of equations (2.21)-(2.23) imply both external equilibrium — i.e. equality between uses and sources of foreign exchange — and equilibrium in the market for the industrial good.

Panel (a) in figure 2.2 plots the saving function (S), the balance of payments identity (BP), and the accumulation function in the (κ, g) space. Both the S and the BP schedules are upward-sloping, but the BP schedule is unambiguously steeper, as $0 < m < 1$. In turn, the accumulation function is independent of κ; it is drawn

for predetermined values of its arguments, including the industrial profit share. All accounting identities and equilibrium conditions are initially satisfied at point A.

Disturbances to this initial equilibrium will elicit compensatory macroeconomic adjustment. In the spirit of the gap literature, I consider two adjustment scenarios. In the first scenario, capital inflows adjust to cover any shortfall of agricultural exports with respect to industrial imports.

This scenario is illustrated in panel (a) of figure 2.2. Consider an increase in z (to $z' > z$), which shifts the accumulation function upwards. Since domestic industry is operating at full capacity, saving-investment balance now requires a higher level of capital inflows, as in point B. Given the new and higher values of g and κ, and the predetermined value of x_a, the balance of payments equation determines the new value of imports of the industrial good as a share of the capital stock (m_m). The higher m_m shifts the BP schedule to the right until it passes through the new equilibrium at point B. In the new equilibrium, accumulation and capital flows are both higher.

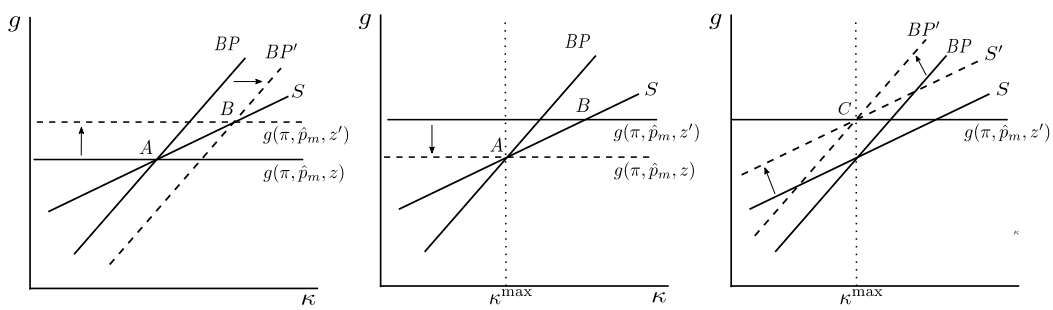
In other words, since agricultural exports are given and domestic industry is operating at full capacity, higher capital inflows are needed to finance higher imports of the two types of industrial goods — both of which are required in proportion to the additional investment. Since excess demand for the domestically produced industrial good is cleared by imports, the industrial profit share remains at its initial value.

In the second scenario, by contrast, limited external financing constrains the rate of feasible capital accumulation. This scenario illustrates the fact that most developing countries face restrictions in international capital markets if the ratio of net borrowing to GDP rises above a perceived threshold of sustainability. To capture this possibility in stylized fashion, assume that κ cannot exceed $\kappa^{\max}$.

Panel (b) of figure 2.2 illustrates this scenario. In the initial equilibrium at point A, capital inflows are at the threshold of sustainability. Now consider again an increase in z. At the new point of goods market equilibrium (B), the trade deficit due to

higher industrial imports requires external financing in excess of the threshold of sustainability. Given that balance of payments constraints do not actuate directly at the level of firms, the typical response in this scenario includes contractionary policies which lower domestic absorption. These policies can be captured with maximum simplicity by a decline in z back to its original level. As we can see, in contrast to the first scenario, the binding foreign exchange constraint prevented an initial shift in the investment function from sustainably increasing the rate of accumulation.

Figure 2.2: Technical change in agriculture in a two-gap model of a small open economy



(a) A Demand Constraint

(b) A Foreign Exchange Constraint

(c) Technical Change in Agriculture

Finally, panel (c) shows that land-saving technical change in agriculture can relax this foreign exchange constraint. With exogenous terms of trade, equation (2.22) implies that land-saving technical change will raise rural saving in terms of the industrial good if $(1+\theta)\beta < 1$. Thus, the S schedule will shift to the left unambiguously in the owner-cultivator case (where $\theta = 0$) and, for plausible parameter values, in the dual scenario as well (movements in the terms of trade, which in the closed economy caused the value of agricultural saving to fall in terms of the industrial good, are ruled out in the small open economy).

Since the industrial market clears with variations in imports (i.e. without changes to the profit share), and $\kappa = \kappa^{\max}$, equation (2.22) shows that to the higher rural saving there corresponds a higher rate of accumulation compatible with market equilibrium. This new rate is shown at point C, where the S' schedule intersects the $\kappa = \kappa^{\max}$ line.

Land-saving technical change also raises agricultural exports, as rural demand for the agricultural good will increase less than output under general conditions — chiefly as a result of Engel's effects.[7] This new level of agricultural exports (obtained from equation 2.19), along with the new feasible rate of accumulation (obtained from equation 2.22) and the $\kappa = \kappa^{\max}$ condition, can be plugged into the balance of payments identity (equation 2.21) to endogenously determine the level of imports of the industrial good (m_m) that is compatible both with external balance and (per Walras law) with equilibrium in the market for the industrial good. Finally, the feasible rate of accumulation can be plugged into the accumulation function in (2.23) to endogenously determine the feasible level of the policy variable z.

Point C in panel (c) illustrates a possible configuration in which the new feasible level of investment is such that $z = z'$ and $g = g(\pi, \hat{p_m}, z')$. In other words, a suitable increase in land productivity allowed the originally intended rate of accumulation — which previously violated the $\kappa = \kappa^{max}$ condition — to be compatible with external balance. Note that, without the expansion of agricultural exports, it would be impossible to sustain this higher rate of accumulation without $\kappa > \kappa^{max}$, that is, without a rate of external borrowing in excess of the threshold of sustainability. It is in this sense that land-saving technical change can relax a foreign exchange constraint on industrial growth.

[7]Indeed, from equation (2.19), it can be readily seen that rural exports will rise if $\eta < \frac{1}{\alpha(1+\theta)}$. Recall that $\alpha = \frac{f(w_a,p)(1-l_m)}{\sigma_a}$ is the ratio of rural demand to domestic output of the agricultural good. With positive agricultural exports, $0 < \alpha < 1$ in the open economy model as well as in the closed economy model. Engel's effects imply that $\eta < 1$. In the owner-cultivator scenario, $\Theta = 0$.

2.4 Conclusion

The model presented in this paper embodied structural characteristics common to several developing countries, including low factor substitutability and hidden unemployment in agriculture. It illuminated the effects of biased technical change in agriculture on industrial accumulation in the short to medium run.

The model showed that, if the industrial sector is constrained by domestic demand, land-saving technical change in agriculture — such as irrigation, fertilizers, and multiple cropping — can promote industrial accumulation by raising rural employment and labor incomes, and thus enlarging the domestic market for manufactures. Hidden unemployment allows industrial growth to accelerate even as agriculture absorbs more workers.

By contrast, labor-saving technical change — such as the mechanization of sowing, harvesting, and threshing activities — may aggravate the problem of hidden unemployment, bid down rural wages, and narrow the domestic market for industrial goods. This outcome is more likely if agriculture possesses a dual structure whereby a class of smallholding peasants and landless workers provides labor to a class of large landowners — as exemplified by the minifundio-latifundio system in Latin America (García, 1966; Barraclough and Domike, 1966). The negative effects of excessive mechanization in unequal agrarian structures are concerning, since a number of studies suggest that inequality in land ownership may itself promote labor-saving biases in technical change (De Janvry, 1978; Sanders and Ruttan, 1978; Sen, 1981; Rao, 2005).

These findings contrast with a recent strand of the literature which has argued that greater labor absorption into agriculture — such as that resulting from land-saving technical change — hurts industrial growth (Matsuyama, 1992; Bustos et al., 2012). The authors' conclusion stems from positing a small open economy with full tradability in both sectors, as well as competitive labor markets and full employment. By linking the intersectoral terms of trade to world prices, the small open economy

framework eliminates demand-side complementarity between agriculture and industry. In turn, the full employment assumption ensures that greater labor absorption into agriculture comes at the expense of higher unit costs and lower employment in industry.

The empirical evidence that motivates this paper, however, shows that these assumptions are unlikely to hold in the average developing country, at least in the short to medium run. These studies have used climate variables for statistical identification, exploring variation in the data which resulted from exogenous changes in land yields (Henderson et al., 2009; Shifa, 2015; de Souza, 2015). They find robust evidence that higher land yields on average elicit a short- to medium-run growth acceleration in the industrial sector.

By contrast, the alternative framework in this paper eschewed full employment and placed the role of domestic demand center-stage. In addition, an extension of the model showed that, even in a small open economy, land-saving technical change may foster accumulation in industry by relaxing foreign exchange constraints which often beset semi-industrial economies. In light of these two contributions the empirical evidence suggests, first, that the industrial sector in most developing countries stands to benefit from lower demand and foreign exchange constraints on accumulation and, second, that technical change in agriculture can ease these constraints.[8]

These findings also illuminate the role of waves of land-saving innovations in the early stages of the industrialization of Japan and East Asia — examining some of the macroeconomic channels of complementary previously noted by scholars in the field (Smith, 1959; Ohkawa and Rosovsky, 1960; Amsden, 1979; Kay, 2001). Similar innovations have spread to other countries in Asia and elsewhere as part of the

[8]As we can see, these combined results validate some of the insights of the literature on the macroeconomic role of agriculture in development, as classically summarized by Johnston and Mellor (1961).

'green revolution', with possibly significant effects on rural employment and domestic demand for industrial goods in those areas as well (Hossain et al., 2006).

Finally, the paper delimited the conditions under which different innovations are synergistic with industrial growth. It did so by showing that the effects of technical change in agriculture depend on the industrial growth regime. In particular, real wage resistance in industry may undermine demand complementarity between the two sectors — extending to a two-sector framework a classical result of post-Keynesian growth theory (Robinson, 1962; Marglin, 1984).

But in accordance with its aim of explaining the aforementioned empirical findings, the paper focused on explaining growth accelerations in the short to medium run. It has thus ignored long-run scenarios in which particular factor-saving biases would support industrialization. An important long-run scenario is the emergence of labor shortages in the wake of sustained industrial growth and urbanization, which would call for labor-saving innovations in agriculture. But labor-saving innovations are best seen as induced by the development of this favorable scenario, not as its independent cause.

Another important long-run scenario may follow from growth strategies centered on the expansion of primary exports. Though in the short-run these strategies may relax external constraints on capital accumulation, in the long-run they may hurt domestic industry by causing real exchange rate appreciation and by rendering the economy vulnerable to terms of trade shocks (Krugman, 1987; Rajan and Subramanian, 2011; Deaton, 1999; Bleaney and Greenaway, 2001).

These scenarios, and the appropriate macroeconomic policies to address them, should be considered in appraisals of the long-run role of agriculture in development. Still, the paper's medium-run scope is useful in cautioning against policies that promote the excessive mechanization of agriculture before labor shortages develop. At the same time, the paper suggests that many developing countries stand to gain from

policies that promote agriculture's dual role as a medium-run outlet for surplus labor and as a source of demand and foreign exchange for industry.

CHAPTER 3

THE POLITICAL ECONOMY OF BIASED TECHNICAL CHANGE IN BRAZILIAN AGRICULTURE (1950-1980)

3.1 Introduction

The pattern of technical change in agriculture during the golden age of Brazil's industrialization exhibited a marked bias towards labor-saving innovations relative to land-saving innovations. Since agriculture is typically characterized by a low elasticity of substitution between land and labor, as well as by a large contribution of effective land to agricultural output, this bias led to a considerable degree of labor displacement.

Traditional theory explains the direction of technical change in agriculture as a response to the evolution of relative factor scarcities (see, e.g. Hayami and Ruttan, 1970). In the absence of severe market failures, a labor-saving bias would reflect the need to release labor from agriculture in the extent necessary to avoid the development of labor supply bottlenecks in the expanding urban sector. In Brazil, by contrast, the labor-displacing character of technical change in agriculture was autonomous with respect to factor prices and far in excess of the labor-absorption capacity of the modern sector.

In light of the need for an alternative explanation for this fundamental bias, this paper contributes a narrative that places center-stage the action of structural and institutional features of Brazil's agriculture. It makes two main contributions. First, using primary and secondary sources it documents the evolving pattern of employment across agricultural establishments, the use of modern labor-saving and land-saving

inputs, and the problem of labor displacement that accompanied the modernization of the dominant segments of Brazilian agriculture.

Second, it examines the role of public policy in shaping the rate and direction of technical change. Particular attention is paid to public policy concerning credit and input prices, research and extension, and rural infrastructure.

Attention to Brazil's dual distribution of operational units, whereby land-abundant units (latifundios) have coexisted with land-scarce and labor-abundant units (minifundios), permeates both contributions. This dual structure casts light on the origin, benefits, and effects of policies concerning technical change.

The main findings of the paper can be summarized as follows. First, with respect to employment trends, I find that the absolute number of wage employees and (within-establishment) sharecroppers fell between 1950 and 1970. This decline resulted from substantial labor shedding among medium and large establishments (from 10 to 10,000 hectares). The decline in employment reflected a lower use of labor per hectare of cultivated land (which declined by 50% among establishments above 100 hectares), and a lower use of labor per establishment.

Second, I find that, as a counterpart to labor displacement among larger establishments, the smallholding sector swelled between 1950 and 1970. Indeed, establishments with less than 10 hectares accounted for 51.2% of all establishments in 1970, up from 34.4% in 1950. Accordingly, the average area per establishment in this category fell from 4.25 to 3.6 hectares.

Third, with respect to the use of modern inputs, I find that, while the adoption of mechanized techniques accelerated sharply in the early 1950s, the use of land-saving techniques lagged behind, only accelerating after the mid 1960s. As a result, aggregate land yield grew slowly throughout the 1950-1980 period. Although non-traditional export crops posted yield gains in the 1970s, these gains were partly offset by declining land yields among domestically-oriented food crops.

In other words, the employment losses verified until the 1970s were a consequence of a labor-saving bias embodied in the combinations of modern inputs adopted by the larger establishments. The 1970s saw a partial recovery of measures of labor absorption among larger establishments, which resulted from the more intensive cultivation practices of non-traditional export crops. Still, this recovery was insufficient to run down the stock of hidden unemployment in agriculture and elsewhere.

Finally, with respect to the policies influencing technical change, I find no evidence that the main policy instruments used to foster the modernization of agriculture during the 1950-1980 period — the concession of implicit price subsidies and of subsidized credit — discriminated in favor of labor-saving inputs.

Rather, I argue that the biases were introduced for two main reasons. First, the subsidy policies disproportionately benefited larger producers who, at any point in the period analyzed, used land far more extensively, and wage and tenant labor far more intensively than smallholdings. To the extent that a trade-off exists between the adoption of land-saving and labor-saving inputs, larger producers stood to reap greater benefits by adopting combinations that economized primarily on labor. In addition, larger establishments faced higher labor disciplining costs in a context of incomplete contracts, and many derived both local monoposonistic power over labor — and political power in general — from control over large tracts of land. These structural features of dualist agriculture provided further impetus for a labor-saving pattern of technical change (Griffin, 1974; Rao, 2005; De Janvry, 1978).

The second reason is the high degree of technical complementarity among land-saving inputs. In general land-saving innovations are brought about by packages of chemical innovations (e.g.: pesticides, chemical fertilizers), biological innovations (e.g.: biological fertilizers, high-yielding varieties), intensive practices (e.g.: multiple cropping), and rural infrastructure (e.g.: irrigation, water control). These individual components are highly complementary (De Janvry, 1978). For example, under

many climatic and soil conditions, crop response to fertilizers is low without water control infrastructure; multiple cropping is inviable without artificial fertilization; high-yielding varieties are vulnerable without the the use of pesticides, etc.

Moreover, the benefits of developing and adapting key components of the required packages are not liable to be appropriated by private entrepreneurs, and as a result the State has played a crucial role in their development and provision. Historically, this role has been manifested in the development of public research and extension agencies, and in public investment in rural infrastructure — such as irrigation and electrification. This paper shows that, during most of the 1950-1980 period, the Brazilian government neglected research, extension, and rural infrastructure.

At the same time, labor-saving innovations (especially tractors) are much less afflicted by market failures, and thus the private sector has historically played a more prominent role in their development and dissemination. Thus, by focusing only on subsidizing the prices of private inputs and credit, the state indirectly promoted a labor-saving bias in technical change, even though the subsidies were themselves neutral.

This paper relates to two branches of the large literature on Brazil's agriculture during the 1950-1980 period. The first branch is comprised of studies that, drawing on the seminal work of Binswanger (1974), have econometrically estimated a sharp decline in the share of labor in total farm costs even after controlling for the evolution of factor prices. This finding is evidence of a Hicks-biased pattern of technical change geared towards economizing on labor (see, e.g. Sanders and Ruttan, 1978; Santos, 1986). The second branch is comprised of numerous papers — described in the section below — that have focused on particular aspects of government policies that impinge on the development or the adoption of agricultural technologies. The present paper makes a contribution to both of these literatures by providing an integrated vision of the relevant policies, and by making explicit their relation to technical change biases.

The remainder of the paper is organized as follows. Section 3.2 provides background on the agrarian structure of Brazil at the time, and on the use and distribution of land. Section 3.3 documents the decline in employment among larger establishments. Section 3.4 describes the main public policies concerning credit and input prices, research and extension, and rural infrastructure. It establishes the unequal distribution of their benefits and their consequences for technical change. Section 3.5 documents the use of modern labor-saving and land-saving inputs during 1950-1980, along with the evolution of land yields across different crops. It documents the labor-saving bias embodied in the composition of these inputs during most of the 1950-1980 period. Section 3.6 concludes the paper, and an Appendix includes additional data tables and figures.

3.2 Background

3.2.1 The Latifundio-Minifundio System

The agrarian structure that characterized Brazil during 1950-1980 is rooted in the latifundio-minifundio system. Three main features have been traditionally associated with minifundios. The first is absolute land scarcity, which often results in the underemployment of the labor capacity of their occupants and compels them to seek complementary sources of income elsewhere. The second are relations of dependence with respect to large landholdings — the latifundios —, in a context in which the latter have privileged access to physical and institutional resources. And the third is the lack of support from public institutions regarding technical assistance, credit, and integration into the national marketing system (García, 1966).

The forms of labor provision to larger properties are shaped by the degree to which the minifundios are integrated with the latifundio system in a given region. In this respect, García (1966) classifies minifundios into four strata. The first stratum includes the minifundios that are located inside the traditional large properties.

Typical arrangements include the formation of 'colonies' of agricultural workers who are allowed to live in designated plots and to cultivate subsistence goods, either in exchange for labor services or in exchange for the agreement to provide a share of the surplus to the latifundio proprietor.

The second stratum includes the 'frontier' minifundios, which are located outside the large properties, but which are often dependent on access privileges to certain physical resources (such as crop processing facilities, pastures, and water). Such access is granted in exchange for work obligations, or for a share in the smallholder's output.

The third stratum include minifundios that are independent of these obligations, but which are nonetheless unable to fully employ their resident workforce. They thus often hire out labor to large properties or become sharecroppers therein. Finally, the fourth stratum includes minifundios with some degree of capitalization and stable relations with the market, thus being halfway between small agricultural enterprises and subsistence holdings.

In Brazil, the latifundio-minifundio system crystallized with the decline of the slavery system in the second half of the 19th century. But the historical literature reveals that even the colonial and early independent economies — characterized by the dominance of export-oriented plantations and by slavery — already portended traits associated with the latifundio-minifundio system. Indeed, even though formal ownership titles were only available to a limited number of wealthy individuals, the norms and conventions governing the usufruct of land were far more permissive. They allowed free workers to settle in unclaimed land or to dwell in and around large properties under a variety of associative arrangements, such as labor obligations, tenancy, and sharecropping (Linhares and da Silva, 1981; da Costa, 1992).

The literature has spawned many examples of these arrangements, including descriptions of small producers using the processing facilities of large sugarcane estates

in the 18th century in exchange for a share in the output (Antonil, 2007; Ferlini, 1986); descriptions of small landholders providing temporary wage labor to neighboring coffee plantations in 19th-century Sao Paulo (Lamounier, Lamounier); and descriptions of the role of non-slaveholders in the supply of food for local markets in the late 18th and early 19th centuries (da Costa, 1992). In addition to the activities carried out by free workers, research has also cast light on the 'peasant practices' of slaves belonging to export-oriented plantations. These activities were geared to the production of subsistence goods and the sales of surpluses in local or even central urban markets (Cardoso, 1979, 1987; Castro, 1980; Linhares and da Silva, 1981; Schwartz, 1983).

New national legislation regulating land ownership was enacted in 1850, at a time when slave labor was increasingly replaced by free workers. It ruled out the possibility of granting ownership titles to those occupying and cultivating homesteads on public and/or unclaimed land, while at the same time making the acquisition of those lands by independent producers virtually impossible, due to the imposition of minimum prices and high registration fees (Dean, 1971; Buainain and Pires, 2003). By preventing the development of a strong, independent family-farming sector, the 1850 legislation also gave new impetus to the forms of labor relations and rent extraction of the minifundio-latifundio system.

Large field studies of land use and labor relations conducted in the 1960s show that, at the height of industrialization in Brazil, the latifundio-minifundio system was still dominant in the countryside. For example, a study by the Brazilian Institute of Agrarian Reform (IBRA) revealed that a total of 6.3 million workers were involved in the various forms of labor arrangements described above, often occupying more than one of these positions over the course of a year (ICAD, 1966; Barraclough and Domike, 1966; Dillman, 1976).

3.2.2 Land Distribution and Land Use

The decennial agrarian censuses carried out by the Brazilian national statistical agency (IBGE) help to illuminate important aspects of the country's agrarian structure in 1950-1980, including land distribution, employment, and the use of intermediate and capital inputs.

The units of observation in the census are agricultural establishments. An establishment is defined as any continuous area dedicated to agricultural activities and subject to a single administration.[1] It may be constituted by the administrators' own land, by third-party land, or by a combination of the two. Importantly, areas cultivated by sharecroppers are considered unique establishments when the sharecroppers are responsible for their administration; but they are considered only part of an establishment when they are subject to an administrator other than the sharecropper.

Table 3.1 shows that, in accordance with the descriptions of the latifundio-minifundio system described above, Brazil has been characterized by extreme land inequality across agricultural establishments. In 1950, establishments with less than 10 hectares (ha) accounted for 34.4% of all establishments, but for only 1.3% of the total agricultural area. By contrast, establishments with more than 1,000ha accounted for just under 1.6% of all establishments, but for 50.9% of the total agricultural area.

Table 3.1 also reveals a swelling of the smallholding sector between 1950 and 1970 which, as further discussed below, is a counterpart of the labor-saving bias that characterized technical change in the larger establishments. Indeed, by 1970 establishments with less than 10ha accounted for 51.2% of all establishments, up from 34.4% in 1950. Accordingly, the average area per establishment fell from 4.25ha to 3.6ha.

[1] Agricultural activities include crop production, livestock breeding and feeding, forestry, and bee and silkworm keeping.

Table 3.1: Share of total establishments, and share of total establishment area, by area group (%)

	< 10 ha		10-100 ha		100-1,000 ha		1,000-10,000 ha		> 10,000 ha	
	Estab.	Area	Estab.	Area	Estab.	Area	Estab.	Area	Estab.	Area
1920	–	–	–	–	24.4	27.6	3.8	37.4	0.26	26.0
1950	34.4	1.3	51.0	15.3	13.0	32.5	1.5	31.5	0.08	19.4
1960	44.8	2.2	44.7	19.0	9.4	34.4	0.9	28.6	0.05	15.6
1970	51.2	3.1	39.3	20.4	8.4	37.0	0.7	27.2	0.03	12.3
1980	50.4	2.5	39.1	17.7	9.5	34.8	0.9	28.7	0.05	16.4

Notes: The table shows the share of establishments of each area group in the total number of establishments ('Estab.' columns), and in the total area of all establishments ('Area' columns). All numbers are in percent of the total. The area groups include establishments with a total area of less than 10 hectares (< 10 ha), of between 10 and 100 hectares (10-100 ha), of between 100 and 1000 hectares (100-1000 ha), of between 1,000 and 10,000 hectares (1,000-10,000 ha), and of more than 10,000 hectares (> 10,000 ha). Source: IBGE Agrarian Census.

Inequality in the size distribution of establishments is reflected in inequality in the intensity with which land is used. The census defined the following categories of land use: cropland (for permanent or seasonal crops), pastures (cultivated or natural), forests (cultivated or natural), and unused but potentially productive land. Figure E.1 in the Appendix shows that establishments with less than 10ha allocated most of their land to crop production (60% in 1950). Cropland retains a sizable share of total land among establishments in the 10-100ha group, but its share steeply declines with establishment size. For example, in 1950 less than 3% of total land in establishments of the 1,000-10,000ha group was dedicated to crop production (among establishments larger than 10,000ha, this proportion was less than 0.1%).

By contrast, the share of natural pastures, forests[2] and unused land rises with establishment size. In 1950, these categories amounted to 90% of total land in establishments of the 1,000-10,000ha group, and to 97.6% of total land in establishments

[2]Cultivated forests made up a small proportion of the total land across establishment groups, and were thus aggregated with natural forests.

larger than 10,000ha. It stands to reason that a small fraction of natural pastures in these establishments are likely to have been used for livestock production.

The share of land used productively retained a remarkable degree of stability between 1950 and 1970. During the 1970s, in turn, this share expanded, particularly among establishments in the 10-10,000ha size groups. This expansion is consistent with a more intensive use of land (and a partial reversal of the labor shedding trend) that occurred in that decade, as further discussed below.

3.3 The Employment Problem

The census defined five main categories of employment in each establishment: the administrators themselves, permanent employees, temporary employees, sharecroppers and, starting in 1960, workers under 'other employment arrangements'. Those receiving either all or most of their compensation in cash were considered employees. Within this group, those working under contracts longer than a year were classified as permanent, while the remainder was classified as temporary. Those classified under other employment arrangements after 1960 included dwellers performing direct labor services in exchange for abode and land usufruct privileges in the establishment. This category became less and less important between 1960 and 1980, with its share in total employment falling from 2.9% to 0.42%. For simplicity, I aggregated them with the sharecropper category. Importantly, all employment categories included unpaid family members aiding those directly responsible for performing the work.

Table 3.2 shows the distribution of total employment across establishment area groups in 1950. As expected given Brazil's dual agrarian structure, establishments with less than 10ha accounted for a large share of rural employment (20.4%) relative to their share in total area (1.3%). But most rural employment was generated by establishments between 10ha and 1,000ha: 72.4% of the total. Establishments above

1,000ha, in turn, accounted for only 7.2% of total employment, despite occupying 50.9% of total area.

The 10-1,000ha group also accounted for most of wage employment (72% of permanent and 75.7% of temporary employees) and for most of sharecropping arrangements subordinated to the establishments' administration (85.4%). As expected, most administrators and their family members found employment in establishments with less than 100ha (84.1%).

Table 3.2: Share of employment categories in 1950, by area group (%).

	< 10 ha	**10-100 ha**	**100-1,000 ha**	**1,000-10,000 ha**	**> 10,000 ha**
Total Employment	**20.4**	**46.1**	**26.3**	**6.4**	**0.8**
Administrators	29.9	54.2	14.2	1.6	0.1
Permanent Employees	3.5	24.6	48.1	19.8	3.9
Temporary Employees	14.7	41.1	34.6	8.8	0.7
Sharecroppers and Others	3.8	40.8	44.6	10.0	0.7

Notes: The table shows the share of establishments of each area group in the total number of workers of various employment categories in 1950. The workers in all employment categories also include unpaid family members. All numbers are in percent of the total of each employment category. The area groups include establishments with a total area of less than 10 hectares (< 10 ha), of between 10 and 100 hectares (10-100 ha), of between 100 and 1000 hectares (100-1000 ha), of between 1,000 and 10,000 hectares (1,000-10,000 ha), and of more than 10,000 hectares (> 10,000 ha). Source: IBGE Agrarian Census.

Table 3.3 shows the evolution of total agricultural employment and of the shares of each employment category. The unequivocal trend between 1950 and 1970 is of a decline in the relative share of wage employment — both permanent and temporary —, and of a decline in the share of within-establishment sharecropping arrangements. The counterpart of this decline is an increase in the share of establishment administrators, which mirrors the relative expansion of smallholdings noted above in Table 3.1. In fact, in can be inferred from Table 3.3 that the *absolute* number of permanent and temporary employees, as well as of within-establishment sharecroppers, *fell* between 1950 and 1970, with the bulk of the decline occurring in the 1960s.

Together, these aggregate trends suggest intense labor shedding in the medium and upper strata of establishment sizes — between 10ha and 10,000 ha — which, despite increasing in absolute number and absolute area, employed less employees and tenants in 1970 than in 1950. The expansion of the smallholding sector, in turn, suggests that it acted as a repository for many of the released workers.

Table 3.3: Total employment across farm establishments and distribution by category

	Total Employment (in millions)	Administrator (% of total)	Permanent Employees (% of total)	Temporary Employees (% of total)	Sharecroppers and Others (% of total)
1950	11.0	54.8	12.9	21.0	11.3
1960	15.6	63.0	9.1	19.1	8.8
1970	17.6	80.2	6.6	8.5	4.7
1980	21.2	73.9	10.3	13.1	2.8

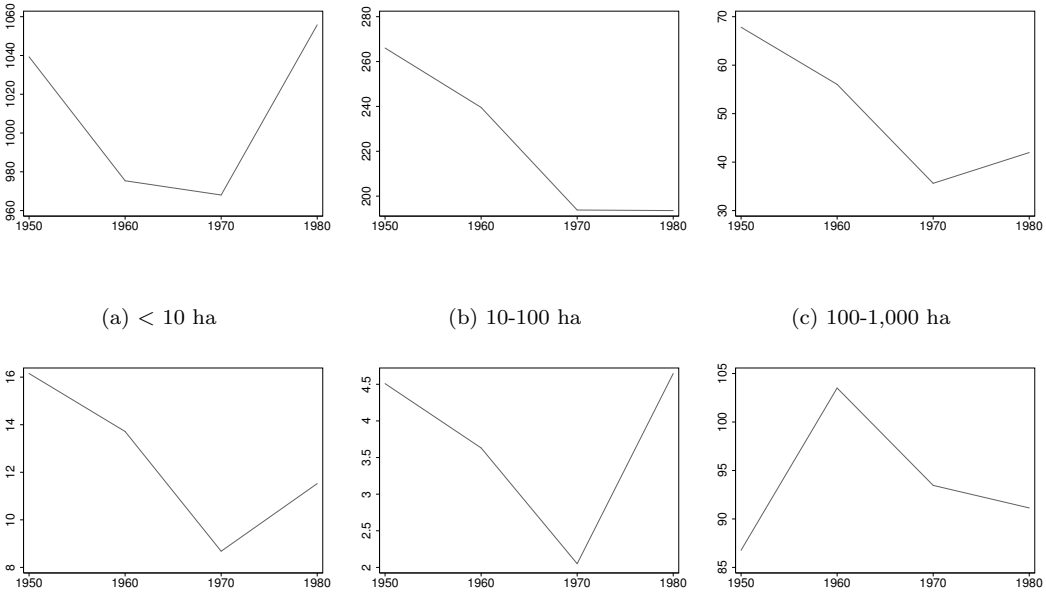
Notes: The table shows the total number of persons engaged in Agriculture (first column), and their distribution by categories of employment. The workers in all employment categories also include unpaid family members. Source: IBGE Agrarian Census.

This inference is supported by Figure E.2 in the Appendix, which shows the average number of workers of each category per establishment, by area group. The first fact that stands out is a decline in the average number of workers per establishment, which went from 5.3 in 1950 to 3.6 in 1970 (panel f, first column). This decline was marked in the establishments above 100ha, and entirely accounted for by the decline in the relative employment of wage workers and sharecroppers (as seen in panels b-e). The smallholding sector, in turn, barely showed a decline in employment per establishment (panel a).

The growth of the larger establishments was also intensive in the "labor-land" space, as attested by figure 3.1. The figure shows the number of workers (of all types) per 1,000 hectares of cropland and pastures, by establishment size group. Panels (b)-(e) show a marked decline in the average labor-land ratio across the larger establishments between 1950 and 1970. The decline approximated 50% among establishments

above 100ha. The smallholding sector also saw a decline in the ratio, although of only 8%. The 1970s saw a partial recovery of the ratio in the larger establishments which, as further discussed in section 3.5, is partly explained by higher yields among export-oriented crops.

Figure 3.1: Labor-land ratios by size group (in persons per 1,000 hectares of cropland and pastures).



(a) < 10 ha (b) 10-100 ha (c) 100-1,000 ha

(d) 1,000-10,000 ha (e) > 10,000 ha (f) All Size Groups

Notes: The figures show the ratio between total persons employed and total area of cropland and pastures, by establishment size group. Total employment includes unpaid family members, permanent employees, temporary employees, and sharecroppers and other arrangements. Total land includes permanent cropland, temporary cropland, natural pastures, and planted pastures. Source: IBGE Agrarian Census.

Figure 3.1 also shows sharp differences in the level of the labor-land ratio across size groups. In 1950, for example, the ratio exceed 1,000 workers per 1,000 hectares among establishments with less than 10ha, but was only 16 among establishments with 1,000-10,000ha, and 4.5 among establishments with more than 10,000ha. This unequal distribution of labor-land ratios by establishment size shows that market transactions fail to eliminate the link between an unequal distribution of land ownership, on the one hand, and an unequal distribution of both land and factor proportions

across operational units, on the other hand (Sen, 1981; Rao, 1986; Ünal, 2009). It also fully explains why, despite the fact that the ratio fell across all size groups between 1950 and 1970, the sector-wide average actually rose, as seen in panel (f). This increase is fully accounted for by the relative expansion of an increasingly land-scarce smallholding sector which provided an outlet for the labor made redundant elsewhere.

3.4 Government Policy and Technical Change

3.4.1 Credit, Price, and Trade Policies

Throughout the period analyzed, the state aimed to shape two fundamental sets of prices relevant for technical change in agriculture: the prices of modern inputs and the price of credit. Until the mid 1960s, the multiple exchange rate regime was the linchpin of both policies. This regime was adopted in 1953, in response to severe foreign exchange shortages that had beset the country in the post-war years. It discriminated against both non-essential imports and traditional exports. Importers of non-essential goods, which included most consumer goods, needed to purchase limited foreign exchange quotas at auctions operated by the Bank of Brazil. The resulting premiums led to depreciated exchange rates. By the same token, traditional exports — primarily coffee and other agricultural commodities — faced appreciated exchange rates.

In return, the regime subsidized non-traditional exports and 'essential imports'. Those importing goods that were considered essential for the industrialization process, but not produced domestically, faced highly appreciated exchange rates. These goods included machinery and intermediate inputs, whose demand had soared with industrialization. Though not used by industry, tractors and chemical fertilizers were also classified in this category.

Figure 3.2 shows estimates of the rate of implicit taxation of agricultural exports, and the rate of implicit subsidization of tractors and fertilizers between 1953 and

1966; these rates were calculated with reference to a purchasing-power parity rate based on the 1938 nominal exchange rate.[3] As we can see, relative to this benchmark agricultural exports were highly taxed during the 1950s, whereas agricultural inputs were highly subsidized.

The input subsidies served a political aim, as they compensated the agricultural sector — in particular the larges farmers, which came to use modern inputs more intensively — for the indirect taxation of export producers. But they also served an economic aim, as they made modern inputs available at a lower price relative to the domestic prices of land and labor. As argued forcefully by Smith (1969), these subsidies were one of the two main instruments on which policy-makers pinned their hopes for the modernization of agriculture.

Figure 3.2: Implicit tax (<0) or subsidy (>0) due to effective exchange rates (in %)

Notes: This figure shows the degree to which the effective exchange rates for exports of agricultural goods, imports of fertilizers, and imports of tractors deviated from an estimated purchasing power parity rate using the 1938 nominal exchange rate as reference. Positive values indicate that trade and exchange rate policies granted an implicit subsidy to those transactions, while negative values indicate that they exacted an implicit tax. Source: Homem de Melo (1979).

The other instrument was subsidized credit. Throughout the period analyzed, the public sector provided the bulk of agricultural credit, with a key role played by the

[3]For more details, see Homem de Melo (1979) and the references therein.

Bank of Brazil. The agricultural credit system was organized in 1937. Until the early 1950s, it focused almost entirely on providing working capital to finance the agricultural production cycle; accordingly, it was managed as a short-run policy instrument. But in 1952 a large reform created long-term credit lines for capital investment — mainly for establishing permanent crops and for machinery —, and secured expanded sources of funding. These sources included mandatory contributions from pension funds and a share of compulsory bank reserves (the Bank of Brazil had monetary authority privileges until the creation of the Central Bank in 1964).

The main source of funding for the reformed system, however, came from the multiple exchange rate system. Even after accounting for the subsidization of non-traditional exports and essential imports, the Bank of Brazil — which was given the monopoly of foreign exchange transactions — earned large quasi-fiscal net revenues from operating the system. The 1953 law destined the bulk of these revenues to finance capital investment in agriculture at low interest. For the remainder of the decade, these revenues provided most of the funding for agricultural credit, often exceeding the Bank's financing needs for that purpose (Munhoz, 1982).

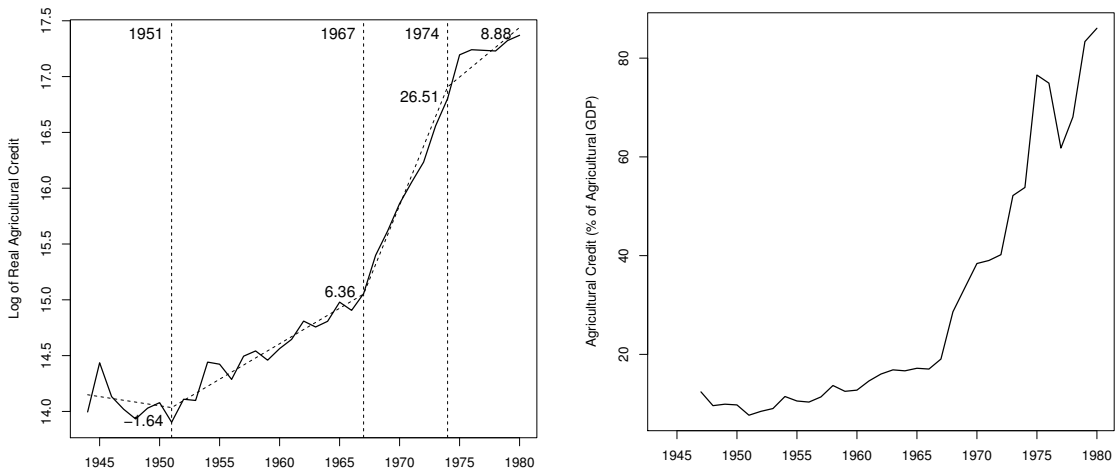
Figure 3.3 shows the evolution of agricultural credit extended by the Bank of Brazil.[4] The solid line in panel (a) shows the stock of real agricultural credit from 1944 to 1980, in log scale. To help identify different subperiods of credit expansion, I used a goodness of fit procedure to endogenously estimate the number and location of structural breakpoints in the growth rate of series (see Bai and Perron, 1998, 2002).[5] The procedure identified four subperiods: 1944-1951, 1952-1967, 1968-1974,

[4]See the notes to figure 3.3 for detailed sources and definitions of agricultural credit

[5]I modeled the growth in real agricultural credit using an exponential model of the form: $ln(cred)_t = a_i + g_i t + \epsilon_t$, where $cred$ denotes the stock of real agricultural credit by the bank of Brazil, t denotes years, and the subscript i denotes different sub-periods. Subject to a minimum segment length and a goodness of fit criterion — both chosen by the researcher —, the Bai-Perron procedure estimates the optimal number of sub-periods i, and the years in which the breaks occurred. As is standard, I chose a minimum segment length of 6 years (the next integer to 15% of the sample size), and used the BIC information criterion.

and 1975-1980. I then fit linear trend models to each subperiod, in order to estimate the within-period growth rate in real agricultural credit. The vertical lines in panel (a) show the breakpoints, while the dashed lines show the linear trend models. The numbers above the dashed lines show the average growth rate of real agricultural credit in each sub-period (in % per year).[6]

Figure 3.3: Total agricultural credit by the Bank of Brazil.



(a) Log of Real Agricultural Credit

(b) Share of Agricultural Credit in Agricultural GDP (%)

Notes: The figures show the evolution of agricultural credit extended by the Bank of Brazil. In all years, the measure of agricultural credit is defined as the outstanding balance of total agricultural credit. The breakdown of total agricultural credit available in the Statistical Yearbook of Brazil varied over the years. The total for 1951-1967 is the sum of current account loans and discounted notes, for both crop and livestock agriculture. The total for 1968-1972 is the sum of production and commercialization credit, for both agriculture and livestock. The total for 1974-1980 is the sum of credit for production, commercialization, and investment in the Portfolio of General and Rural Credit ("Carteira de Credito Geral e Rural") of the Bank of Brazil. The Statistical Yearbooks did not report credit numbers for 1973 and 1977, which were linearly interpolated. The solid line in Panel (a) shows the logarithm of real agricultural credit. The vertical lines indicate the years in which a structural break in the growth rate of real agricultural credit was identified by the Bai-Perron procedure. The dashed lines show the linear models fit for each of the resulting subperiods. The numbers above the dashed lines show the slope of the linear model, i.e. the average growth rate of real agricultural credit in each sub-period (in % per year). The linear models and growth rates were estimated using the procedure in Boyce (1986a). Sources: IBGE Statistical Yearbook of Brazil, various years (for agricultural credit); Fundacao Getulio Vargas, for the general price index (IGP-DI); and IBGE, for agricultural GDP.

[6]To avoid discontinuity biases, after the estimating the breakpoints, I re-estimated the trend models with a restriction to ensure that the trendlines meet at each breakpoint (see Boyce, 1986a, for more details).

As we can see, after a moderate decline in 1944-1951, a period of sustained growth in agricultural credit began in 1952, coinciding with the reform of the system and the subsequent inflow of operational funds from the multiple exchange system. From 1952 until 1967, the average rate of expansion in real credit exceeded 6% per year. Accordingly, the ratio of rural credit to value added in agriculture rose from just over 7% in 1951 to almost 20% in 1967, as shown in panel (b).

In addition to expanding the volume of credit, the state used its control over the Bank of Brazil to grant sizable subsidies to agriculture by charging negative real interest rates. Granted, nominal rates throughout the 1950s and early 1960s were subject to government controls. As a result, effective real interest rates for both depositors and borrowers were often negative, despite the additional fees and commissions charged by private banks (Christoffersen, 1969; Syvrud, 1972). Still, the existing evidence suggests that interest rates for agriculture received further subsidies and remained consistently below average market lending rates.

Table 3.4 shows the nominal and real rates charged by the Bank of Brazil for tractor acquisition, along with the WPI inflation rate. As we can see, real rates were consistently negative, especially in the first half of the 1960s and second half of the 1970s. Even though data for the 1950s are not available, a conservative upper bound can be obtained by examining average market lending rates, which were also negative during most of the decade.

A number of policy changes in the early 1960s led to a reform of the rural credit system, and to yet another growth acceleration in the volume of subsidized credit. First, as part of an effort revert the anti-export bias of trade and exchange rate policies, the multiple exchange system was abolished in 1961. At once, this change reduced a source of subsidies for imported agricultural machinery and inputs, and deprived the Bank of Brazil from its main source of funding for rural credit.

Table 3.4: Bank of brazil interest rates for tractor acquisition and average market lending rates (%/year)

	Interest Rates for Tractor Acquisition		Average Market Lending Rates		Inflation
	Nominal	Real	Nominal	Real	
1952			14	2.4	11.4
1953			13	-7.1	21.6
1954			13	-9.6	25.1
1955			13.8	1.4	12.2
1956			14.5	-9.2	26.1
1957			15.1	9.2	5.4
1958			16	-8.0	26.1
1959			17.5	-14.7	37.7
1960			18.6	-9.3	30.7
1961	8	-28.1	18.2	-21.3	50.2
1962	9	-29.3	21	-21.5	54.1
1963	11	-39.0	27.5	-29.9	82.0
1964	11	-40.5	33.2	-28.6	86.5
1965	17.25	-13.8	36.9	0.6	36.1
1966	17	-14.6	32.7	-3.2	37.0
1967	18	-5.1	34.1	7.9	24.3
1968	15	-7.6	33.7	7.4	24.5
1969	15	-3.4	30.9	10.0	19.0
1970	15	-3.7			19.5
1971	15	-3.8			19.5
1972	15	-0.6			15.7
1973	15	-1.1			16.3
1974	15	-14.2			34.1
1975	15	-11.5			29.9
1976	15	-21.6			46.7
1977	15	-16.7			38.1
1978	15	-18.7			41.5
1979	38	-23.1			79.4
1980	38	-34.5			110.6

Notes: The table shows (i) the mandated nominal interest rates — with the corresponding real interest rates — charged on loans for tractor acquisition through the national system of rural credit centered on the Bank of Brazil; and (ii) the average market lending rates charged by private banks (inclusive of fees and other charges), also with the corresponding real interest rates. The real rates were computed with reference to the general price index (IGP-DI). Sources: Sanders (1974) and Sayad (1984), for nominal interest on loans for tractor acquisition; Christoffersen (1969) (until 1967) and Syvrud (1972) (after 1967) for average market lending rates; Fundacao Getulio Vargas, for the general price index (IGP-DI).

Second, as part of the overall model of import substitution industrialization, domestic production of tractors was established between 1959 and 1961 (Amato Neto,

1985). The models produced domestically were instantly given tariff protection from similar, imported models. As a result, for the remainder of the 1960s tractor imports were restricted to high-horsepower models, and by 1970 they had declined to negligible levels (Sanders, 1974).

Domestic production of tractors benefited from pecuniary and non-pecuniary externalities bestowed by the growing domestic automotive industry, which led to the attainment of fast reductions in unit costs. In addition, in 1967 the government exempted the tractor industry from the industrial products tax, and from tariffs on capital good imports. As a result, before the end of the decade domestic tractor prices had converged to international levels (Homem de Melo, 1979; Graham et al., 1987).

The early 1960s also saw an effort to promote domestic production of fertilizers. The exchange rate reform of 1961 was followed, in 1966, by the introduction of tariffs and other import restrictions. Unlike tractor imports, however, fertilizer imports remained considerable throughout the 1960s and 1970s. Until the mid 1970s, the share of domestic fertilizers in total apparent consumption of chemical (NPK) fertilizers remained similar to its level in the 1950s. Domestic production remained concentrated in simpler varieties of nitrogen and phosphate fertilizers; the production of more concentrated varieties only began in the 1970s, and by the end of the decade domestic production of potassium fertilizers had yet to begin (Ferreira and dos Anjos, 1983).

Data from the State of Sao Paulo indicates that the policy shift led to a sharp increase in the average real price of chemical fertilizers in the initial years after 1961 — by 1965, this average price had more than doubled relative to its value in 1960. Starting in the mid 1960s, however, international fertilizer prices declined substantially, undoing most of the negative impact of the policy shift. Average prices returned to the levels they had in the 1950s until the energy shocks of the mid 1970s brought a worldwide increase in fertilizer prices (Ferreira and dos Anjos, 1983).

The third policy change was the implementation of a system of incentives for promoting the growth and diversification of agricultural exports. The main aims were to diversify the export portfolio away from coffee — which had seen a boom in the post-war years and accounted for the bulk of agricultural exports —, and to increase the share of processed as opposed to raw agricultural exports.

The government thus adopted a set of policies designed to offset the anti-export bias that had weighted on the agricultural goods. Importantly, however, the bulk of the benefits accrued to producers of processed agricultural goods, as opposed to the agricultural producers themselves. Processing industries were given direct premiums, tax exemptions, and drawbacks on trade tariffs in return for exports. In addition, the government implemented quantitative export restrictions on raw goods, leading domestic producers to supply processing industries at a cost below that of world markets. As a result, by the mid 1970s the implicit subsidies for raw agricultural exports had remained negative, while the implicit subsidies for processed agricultural goods had become positive and large (Graham et al., 1987).

In sum, the end of preferential exchange rates for imported tractors and fertilizers reduced the implicit financial transfers to agriculture that, until the mid 1960s, had operated through input prices. In turn, the adverse shift in agriculture's terms of trade relative to processing industries failed to undo the implicit taxation of agricultural exports. In the face of these developments, compensatory transfers to agriculture, which before occurred through both subsidized input prices and subsidized credit, now fell almost entirely on subsidized credit. It is not surprising therefore that the rural credit policy received a major overhaul in 1965, under considerable influence of rural interests in congress (Nóbrega, 1985).

This overhaul occurred amid a broad reform of the financial system, which included the creation of the Central Bank of Brazil in 1964. Despite efforts to increase the provision of rural credit by private banks, the Bank of Brazil remained the cen-

terpiece of the system. The main sources of funding included demand deposits held with the Bank of Brazil and, increasingly, transfers from the Central Bank. During the 1970s and 1980s, these transfers were an important mechanism for expanding the monetary base. Although it is impossible to know the destination of these transfers exactly (as they were recorded as a single item in the Bank of Brazil's balance sheet), rough estimates indicate that sales of public debt instruments and expansion of the monetary base amounted to between 20% and 30% of total funding for rural credit until the mid 1970s, and to nearly 50% in the late 1970s and early 1980s, as inflation accelerated and increased the flow of subsidies to borrowers (Sayad, 1984).

Figure 3.3 shows that a remarkable acceleration in the stock of rural credit by the Bank of Brazil occurred after the reform. The Bai-Perron test indeed identified a structural break in 1967, and between 1968 and 1974 the real value of rural credit grew by an average of 26.5% per year. During 1975-1980 growth slowed down, but remained respectable at 8.8% per year. Data for the mid 1970s shows that around 25% of the stock of credit was directed for long-term financing of capital formation, primarily the acquisition of machinery[7].

The reform also maintained strict state control over interest rates. As before, both the Bank of Brazil and private banks were required to charge below-market nominal interest rates for rural credit. The implied real interest rates remained negative throughout the 1965-1980 period, especially after inflation began to accelerate again in 1973. As shown in table 3.4, nominal rates for tractor financing were fixed at 15% per year from 1968 to 1978, while inflation averaged 27% per year. Rates for the acquisition of fertilizers were even lower during the mid 1970s (Homem de Melo, 1979) .

[7]Source: Statistical Yearbook of Brazil, 1975-1981 (see also the notes to figure 3.3)

3.4.1.1 The Distribution of Subsidies

As noted above, the system to subsidized credit and, at least until the early 1960s, the system of subsidized imports of tractors and chemical inputs were the main mechanisms through which the agricultural sector received compensatory transfers from the non-agricultural sector. They were also the main instruments deployed by the State to step up the rate technical progress in agriculture.

The distribution of these transfers, however, was heavily concentrated on the larger establishments which, in the eyes of policymakers, were poised to lead the modernization of Brazilian agriculture. They benefited, first, because compared to smallholdings modern inputs made up a greater share of their total expenditures. Any price subsidy therefore had a greater proportional impact on their costs. As suggested by Sanders and Ruttan (1978), the combination of subsidies for modern inputs, on the one hand, and interregional differences the production techniques, on the other hand, can explain changes in the pattern of comparative advantage in the production of important crops during the 1950-1980 period. These changes often hurt backward regions (such as the Northeastern states), which were characterized by a greater share of smallholdings and by a lower use of modern inputs.

The larger establishments also benefited from the fact that, throughout the period analyzed, public rural credit remained concentrated on larger establishments. Panel (a) of Figure 3.4 shows the share of establishments in each size group that reported to have received credit from public sources in the indicated years.[8] The agrarian census of 1950 did not include a questionnaire about credit, but one can infer that the share of establishments receiving credit must have been quite low across size groups. Indeed in 1960, which is midway through the first expansion period, only

[8]Public credit was almost entirely dominated by the Bank of Brazil throughout the period analyzed. Public rural credit also thwarted private rural credit — public sources accounted for 78% of the total value of credit in 1970, and for 86% in 1980.

2.8% of establishments in the 10-100ha group reported to have received credit in that year. The proportion was higher among establishments in the upper size brackets, but it barely exceeded 10%. In turn, at 0.6% the share of smallholdings receiving credit was negligible.

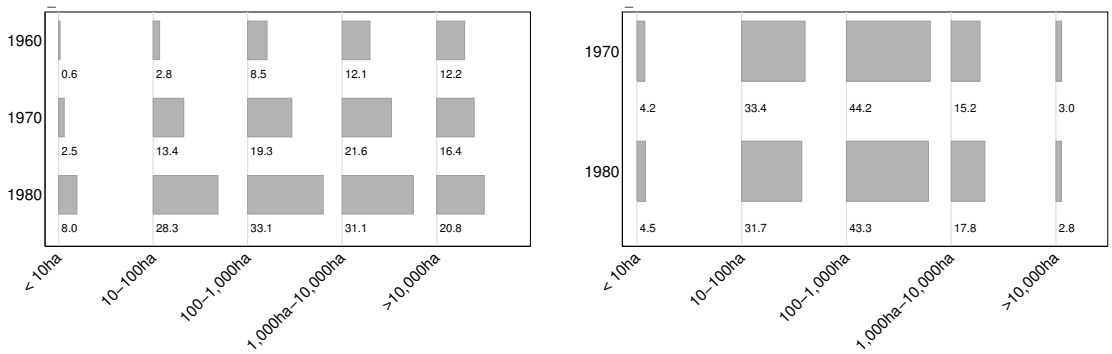
By 1970, shortly after the end of the first expansion period, public credit had become more widely disseminated among the dynamic segments with areas between 10ha and 10,000ha — 13.4% of the establishments in the 10-100ha group, and around 20% of the establishments in the 100-10,000ha groups reported to have received credit that year. In 1980, after the marked expansion of the 1970s, around 30% of the establishments in these brackets reported to have received credit. By contrast, at 2.5% in 1970 and 8% in 1980, the share of smallholders with access to credit remained low.

Panel (b) shows the distribution of the total value of loans in 1970 and 1980 across size groups. The bulk of this value was concentrated in the dynamic segments. The 10-10,000ha size groups accounted for 48.4% of all establishments in 1970, but received 92.68% of the total value of public loans that year.

The distribution of loans by value across establishment size groups, despite being unequal, was stable between 1970 and 1980. But Graham et al. (1987) present evidence that the intraportfolio distribution of loan sizes became more unequal in the period: loans for crop agriculture classified as large accounted for 20% of the total loan value in 1966; by 1976, that proportion had risen to 53%.[9] By the same token, the Gini coefficient of loan values across 34 size categories went from .60 in 1969 to .71 in 1979.

[9]Loans were classified as large if they exceed 500 times the going value of the monthly minimum wage.

Figure 3.4: Dissemination and distribution of credit from public sources.



(a) Share of Establishments that Obtained Credit From Public Sources (% of total in size group)

(b) Share of Size Group in the Total Value of Loans from Public Sources (% of total credit value)

Notes: Panel (a) shows the share of establishments of each size group that reported to have obtained external credit from public sources in the indicated year. Data for 1960 refers to 1959. Panel (b) shows the share of each size group in the total value of loans from public sources in the indicated years. Public sources include state-run banks and government agencies. They accounted for 78% of the total value of credit in 1970, and for 86% in 1980. Source: IBGE Agrarian Census.

As shown in figure 3.3, by the end of the 1970s the value of rural credit from the Bank of Brazil alone had reached around 80% of agricultural value added. This fact, in conjunction with greater inequality in loan values, suggests that agricultural credit is likely to have exceeded the financing needs of most of the benefited establishments, leading to the diversion of internal funds to investment opportunities in assets outside of agriculture (Sayad, 1984; Graham et al., 1987).

Finally, Helfand (2001) shows that, controlling for establishment area, producers growing tradable commodities with high world prices were more likely to receive subsidized credit, indicating discrimination in favor of export commodities — as described in section 3.5 below, this discrimination in credit markets correlated with an uneven evolution of land yields across crops.

This section reviewed the two main policy instruments utilized by the state to promote the use of modern inputs: the concession, until the mid 1960s, of subsidies for importing tractors and chemical inputs; and the massive expansion of subsidized

credit for input acquisition throughout the period of analysis. No evidence exists that, by themselves, the subsidies granted by these policies introduced particular factor-saving biases. Indeed, as indicated by the subsidies for the acquisition of tractors and fertilizers, the subsidies per dollar seem to have been similar for land-saving and labor-saving inputs.

And yet, as seen in section 3.3 (and in section 3.5 below), technical change in the sector did exhibit a labor-saving bias. Thus, a plausible explanation for the observed bias is the very unequal distribution of these subsidies across establishment sizes, loan sizes, and crops. As a result, the policies disproportionately benefited producers who were more likely to favor labor-saving innovations as a result of higher supervision and effort-extraction costs, and to resist land-saving innovations in order to preserve monoposony power in local labor markets and political influence (Griffin, 1974; Rao, 2005; De Janvry, 1978).

A second reason, as suggested in the Introduction, is the fact that land-saving innovations require packages of complementary inputs, such as irrigation and water control, improved farming practices, etc. In most successful cases of agricultural transformation, the state has played a crucial role in the provision of these complementary inputs by investing in research and extension, and in rural infrastructure. It largely failed to do so in Brazil, as the next two sections show.

3.4.2 Research and Extension

As described in the Introduction, labor-saving innovations are typically embodied in mechanical inputs, whereas land-saving innovations are typically embodied in packages combining complementary chemical, biological and infrastructural inputs, as well as blueprints for intensive crop and livestock management practices.

Under most legal systems, the benefits of developing mechanical innovations are liable to be privately appropriated. Moreover, once developed these innovations are

embodied in private goods that can be traded internationally and that often, as in the case of tractors, require little adaptation to local conditions. Finally, by reducing labor costs without having a strong effect on output, they typically allow for adopters to privately appropriate most of the cost savings. These characteristics of mechanical innovation allow for a strong participation of the private sector — including domestic and multinational firms — in their generation and diffusion.

With regard to land-saving innovations, on the other hand, the benefits of developing key components of the required packages are not liable to be appropriated by private entrepreneurs. The resulting market failures have required collective institutions to play a crucial role in their development and provision. These collective institutions have included international agencies, national and regional agencies funded by the state, and sectoral agencies funded by interest groups (de Janvry and Dethier, 1985).

To be sure, some of the innovations that comprise land-saving packages can be profitably provided by private firms. Examples include hybrid seeds whose genetic characteristics are lost after a single use, or pesticides that can be patented. But due to the inherently complementary character of land-saving innovations, they must often be combined with fertilizers, water control infrastructure, and intensive agronomic practices that more closely resemble collective goods. Moreover, even privately developed land-saving inputs often cannot be traded internationally without adaptation to local conditions. In this case, the incipient indigenous research capabilities of many developing countries may require public and other collective institutions to agglutinate the required financial and technical resources to carry out such adaption.

As a response to these challenges, national agricultural research agencies were instituted by most Latin American countries in the late 1950s and early 1960s. Although primarily funded by the State, these agencies operated with a fair degree of autonomy from the government bureaucracy in order to attract qualified researchers

and engage in long-term projects. In their first decades of operation, their main focus was on adapting international technologies to local conditions and ensuring their dissemination through a network of extension stations (Pineiro and Trigo, 1983).

Despite this continental trend, the Brazilian public network of research and extension remained severely underdeveloped during most of the 1950-1980 period. In fact, Brazil lacked a national research agency operating according to the aforementioned model until the establishment of the Brazilian Agricultural Research Corporation (Embrapa), along with its related extension network, in 1974. Although Embrapa represented a qualitative leap for agricultural research in Brazil, its initial focus on biological technologies with long gestation periods meant that its projects did not begin to bear fruit until the late 1970s — essentially falling out of the period of fast industrialization analyzed in this paper (Gonçalves Neto, 1997).

Until then, public agricultural research at the federal level was of small scale and consensually regarded as ineffective. Most federal research efforts were subordinated to the Ministry of Agriculture, suffering from low budgets, bureaucratic hurdles on hiring and compensation, low levels of qualification among researchers, and poor integration with extension services (Schuh, 1970; Pastore and Alves, 1984). Surveys indeed revealed that in 1965 the Federal research program employed less researchers than the program administered by the State of Sao Paulo, which also invested more on agricultural research than the Federal government until the creation of Embrapa (Smith, 1969; da Silva et al., 1980).

Federal support for extension has received a more positive evaluation although it, too, fell short of achieving the required scale of operation. The centerpiece of the system were the Rural Credit and Technical Assistance Associations (Acars). The first Acar was created in the state of Minas Gerais in 1948 and initially operated with joint support from the State government and the American International Association for Economic and Social Development (AIA). It spawned similar organizations in

other states, which in 1956 formed a national network (Abcar). In 1964, the Federal government created an agency designed to promote the Acar system while preserving its administrative autonomy. By the mid 1960s, the Federal government had become the main source of funds for the Acars (Schuh, 1970).

As federal involvement in the system increased, the Acars transitioned from a model focused on providing small loans and technical assistance to small producers to a model focused on larger farmers (Gonçalves Neto, 1997). The shift towards larger producers was reinforced when, in 1969, the Central Bank conditioned access to the program of subsidized credit to the use of technical assistance (Galletti, 1974). As seen above, subsidized credit was heavily concentrated on the more dynamic and larger establishments.

Despite encouraging evaluations of cases in which Acar's actions were able to raise land yields (see, e.g. Ribeiro and Wharton Jr, 1969), the Acar system only reached a small share of Brazilian municipalities, and in the 1960s it was still smaller than the extension system administered by the state of Sao Paulo (Smith, 1969). With the creation of Embrapa in 1974, the Abcars were extinguished and replaced by a network of state-based extension agencies, coordinated by a central agency.

Given the absence of an effective national research program, the only successful cases of research and extension until the creation of Embrapa came through the efforts of crop-specific agencies or through the effort of agencies funded by individual states.

A successful example of a crop-specific agency is the Executive Planning Commission for Cacao (CEPLAC). Created in response to a sectoral crisis in 1957, it was funded through a federally-enforced export tax on raw and processed cacao beans. Its operational model integrated research and extension, resulting in impressive yield gains through the 1960s and 1970s. Another example comes from the corn sector: in the early 1950s, a joint venture of the International Basic Economy Corporation (IBEC) and local researchers gave rise to a strong research program under the

Agroceres corporation. Their development of hybrid seeds in tight cooperation with producers led corn to be one of the few domestically-oriented crops that saw yield gains in the 1950-1980 period (see section 3.5).

Regarding state agencies, it is a consensual view that the State of Sao Paulo ran the only effective programs at a large enough scale. It included a research agency funded by the state's secretariat of agriculture (the Agronomic Institute of Campinas, IAC) and its own extension network (Sao Paulo did not participate in the Acar system). Its focus was on the State's main export crops. For example, beginning in the 1930s the IAC ran a successful cotton research program which led to the development and dissemination of high-yielding varieties (see Ayer and Schuh, 1972, for a positive evaluation). A similarly successful program developed a high-yielding variety of coffee in the 1940s.

Most of these programs exemplify cases of successful collective action by homogeneous interest groups who often held a common stake in a crop, were concentrated geographically, faced an elastic demand for their output, and wielded significant political power. They were able to form crop-specific private research agencies or, more commonly, to induce state authorities to create research programs focused on their activities.

In sum, the development of national institutions of research and extension during the period was generally slow (even for Latin American standards) and insufficient. The founding of Embrapa represented a qualitative leap, but its benefits fell largely out of the period analyzed. Using the terminology of de Janvry and Dethier (1985), the state failed to 'act from above' by designing national-level research programs reflecting a wide spectrum of priorities. By contrast, most examples of success were concentrated on a handful of crops, often under the influence of powerful interest groups of large producers which were able to activate the state 'from below'.

3.4.3 Rural Infrastructure and Other Policies

As with research and extension, the development of rural infrastructure was uneven and generally insufficient, especially until the 1970s. Domestic food supply was widely perceived to be price inelastic in the short run, a perception that was reinforced by episodes of food price inflation during the 1950s and early 1960s. The policy consensus at the time blamed supply rigidities on poor marketing, storage, and distribution infrastructure. Accordingly, these areas were the main focus of public investment.

In the second half of the 1950s, the Brazilian government undertook an ambitious program of infrastructural investment aimed at supporting the deepening of import substitution industrialization toward consumer durables and capital goods. A hallmark of this program was the development of a modern road network — a process which, along with the development of the local auto industry, continued apace throughout the rest of the period analyzed (Lessa, 1964). The dramatic expansion of the road network was supplemented by the development of public and private storage facilities, and of infrastructure for the wholesale distribution of agricultural produce in the main urban areas.

The expansion of transportation, storage, and marketing infrastructure has been credited with reducing wedges between farm gate and urban wholesale prices of agricultural goods (Smith, 1969). At the same time, however, it enabled agricultural growth to proceed in an extensive manner, further contributing to the maintenance of the existing pattern of land use (Nicholls, 1975). By contrast, public investment was insufficient in other types of infrastructure that, due to technical complementarity, could lead to a greater degree of adoption of land-saving inputs.

Irrigation provides a telling example. Contemporary studies have shown that a large share of the country's agricultural area stands to benefit from irrigation (Christofidis, 1999). Localized studies during the period analyzed had also pointed

to the benefits of irrigation in several areas, including the semi-arid and densely populated areas of the Northeastern states, and rice agriculture in the Southern region (Schuh, 1970).

Table 3.5: Share of cultivated land under irrigation, by area group (%)

	< 10 ha	10-100 ha	100-1,000 ha	1,000-10,000 ha	> 10,000 ha
1950	–	–	–	–	–
1960	1.13	1.02	0.87	0.89	0.76
1970	1.02	1.29	1.33	1.18	0.98
1980	1.74	1.31	1.34	1.09	0.84

Notes: The table shows the share of cultivated land under irrigation, by establishment area group. Cultivated land includes permanent cropland, temporary cropland, and cultivated pastures. The area groups include establishments with a total area of less than 10 hectares (< 10 ha), of between 10 and 100 hectares (10-100 ha), of between 100 and 1000 hectares (100-1000 ha), of between 1,000 and 10,000 hectares (1,000-10,000 ha), and of more than 10,000 hectares (> 10,000 ha). Source: IBGE Agrarian Census.

Due to the lumpy character of investment projects in irrigation and water control, the state has often played a role in implementing the required infrastructure. But despite the potential benefits, investment in irrigation projects had been low before 1950, and remained low throughout the 1950-1980 period. Table 3.5 shows that in 1960 less than 1% of cultivated land (including cropland and cultivated pastures) was under a system of irrigation of any kind. Interestingly, little variation existed across establishments of different sizes. This share barely changed in the following twenty years.

The neglect of irrigation and water control infrastructure is concerning, as studies in other contexts have suggested that it enhances crop response to fertilizers and the performance of high-yielding varieties (Ishikawa, 1967; De Janvry, 1971; Boyce, 1986b; Banerjee, 2010).

The low investment in rural electrification until 1970 provides another example of uneven development in rural infrastructure. Indeed, table 3.6 shows that in 1970 less than 3% of all agricultural establishments purchased electricity from other par-

ties, such as public utility companies (a much smaller proportion generated its own electricity). Again, little variation occurred across establishment sizes.

Investment in electrification fared somewhat better in the 1970s, but it the benefits were concentrated on the larger establishments. By 1980, the share of establishments in the 10-10,000ha area groups with access to purchased electricity had risen to around 14%, while the figure for smallholdings was only 5%.

Table 3.6: Share of establishments using purchased electricity, by area group (%)

	< 10 ha	10-100 ha	100-1,000 ha	1,000-10,000 ha	> 10,000 ha
1950	–	–	–	–	–
1960	–	–	–	–	–
1970	2.5	4.1	4.0	4.9	3.2
1980	5.5	14.0	13.8	15.9	8.5

Notes: The table shows the share of establishments that declared to have acquired electricity from other parties (including public utility companies). The area groups include establishments with a total area of less than 10 hectares (< 10 ha), of between 10 and 100 hectares (10-100 ha), of between 100 and 1000 hectares (100-1000 ha), of between 1,000 and 10,000 hectares (1,000-10,000 ha), and of more than 10,000 hectares (> 10,000 ha). Source: IBGE Agrarian Census.

Public investment programs for agriculture focused on transportation, storage, and commercialization infrastructure, while short-changing irrigation, electricity, and other complements to private land-saving inputs. As a result, they gave further impetus to a land-extensive pattern of growth centered on the larger and more dynamic establishments. These uneven priorities combined with a generalized underinvestment on basic and applied education, particularly in rural areas, and further contributed to hold back the adoption of land-saving innovations.

3.5 Modern Inputs and Land Yields

3.5.1 Use of Tractors and Fertilizers

It is a consensual view that, at the start of the period under study, the use of modern inputs was extremely low across most of Brazilian agriculture, save for few

exceptions (see, e.g. Nicholls and Paiva, 1965, for a detailed description based on extensive fieldwork). The policies just reviewed were successful at igniting a process of technical modernization although, not surprisingly given the foregoing analysis, they introduced marked labor-saving biases, especially until the 1970s. This section documents this uneven process of modernization, showing that, while the adoption of mechanized techniques responded promptly with a sharp acceleration in the early 1950s, the use of land-saving techniques lagged behind, at least until the 1970s.

Before recent editions, the agrarian censuses brought limited information on the use of modern inputs at the level of agricultural establishments. Still, it is possible to discern the main trends in the use of labor-saving and land-saving inputs by the existing data on the use of tractors and fertilizers.

Table 3.7 shows different indicators of tractorization by establishment size group. The first set of columns shows the average number of tractors per 1,000 establishments, the second set shows the average number of tractors per 1,000ha of cultivated land (i.e. excluding natural pastures, forests, and unused land), and the third set shows the number of tractors per 1,000 workers, excluding the administrator's family members. The table shows both the level and the compound annual growth rate of these indicators.

The table highlights, first, the low utilization of tractors in 1950 across establishment sizes. It can be inferred that only a small fraction of establishments possessed a tractor, and that tractorization was low even among the larger establishments. The three decades following 1950, however, witnessed a revolution in the use of tractors. By 1980, the average number of tractors per establishment had increased over 25 times nationwide, including an increase of over 100 times among establishments of the 10-100ha area group. Similarly large increases can also be discerned for the the number of tractors per area of cultivated land and per worker. As shown by Sanders

and Ruttan (1978), tractorization accelerated in most regions, but it was particularly strong in the more advanced agricultural areas of the South and Southeast.

Interestingly, establishments above 10ha show a remarkable degree of convergence regarding the tractor-to-worker ratio. While the coefficient of variation of this ratio across these area groups was 0.63 in 1950, it had declined to 0.05 in 1970. This convergence reflects a faster rate of adoption of tractors relative to workers among establishments of the 100-1,000ha area group and, especially, of the 10-100ha area group. As seen above, together these establishments accounted for the lion's share of wage employees and (within-establishment) sharecroppers in Brazilian agriculture. The spread of tractorization across these establishments is thus a prime proximate cause of the relative and absolute declines in labor absorption outside of the small-holding sector.

This implied convergence in factor proportions in the 'labor-tractor' space also suggests that the techniques the were profitably made available to the rapidly-modernizing segment of medium establishments were similar to those available to the segment of larger establishments, a phenomenon classically described by De Janvry (1971) and De Janvry and Martínez (1972) with respect to Argentinean agriculture.

Most soils in Brazil are considered low in nutrients (especially phosphate) and high in acidity. As a consequence, there is great potential for increasing yields by using chemical fertilizers and lime. For example, estimates for the early 1960s claimed that about a third of the cultivated land required the use of lime to lower soil acidity (Schuh, 1970).

Starting in 1960, the agrarian census began to collect information on the use of both chemical fertilizers and lime. Unfortunately, the questionnaire only asked whether establishments used either of these inputs — with no quantitative information about consumption or area coverage. The information is summarized in Table 3.8. Despite the limitations of its binary character, the table confirms the notion that,

Table 3.7: Indices of tractor utilization, by area group

		Tractors per 1,000 Establishments		Tractors per 1,000 Hectares[a]		Tractors per 1,000 Workers[b]	
		Level	Annual Growth	Level	Annual Growth	Level	Annual Growth
< 10 ha	1950	0.1		0.05		0.20	
	1960	2.0	32.1%	0.70	30.9%	3.67	34.0%
	1970	4.8	9.4%	1.91	10.6%	29.47	23.2%
	1980	11.3	8.9%	4.45	8.8%	47.82	5.0%
10-100 ha	1950	1.1		0.10		0.64	
	1960	14.0	29.1%	1.22	28.2%	8.99	30.3%
	1970	35.3	9.7%	3.22	10.2%	51.51	19.1%
	1980	116.9	12.7%	7.89	9.4%	119	8.7%
100-1,000 ha	1950	15.4		0.31		2.03	
	1960	87.3	18.9%	1.56	17.4%	13.30	20.7%
	1970	153.4	5.8%	2.86	6.2%	48.11	13.7%
	1980	414.1	10.4%	4.63	4.9%	94.32	7.0%
1,000-	1950	85.9		0.39		4.37	
-10,000 ha	1960	290.9	13.0%	1.06	10.4%	16.82	14.4%
	1970	559.5	6.8%	1.70	4.9%	52.82	12.1%
	1980	1484.7	10.3%	2.26	2.9%	102.86	6.9%
> 10,000 ha	1950	209.8		0.34		4.15	
	1960	647.5	11.9%	0.76	8.6%	18.68	16.2%
	1970	1385.8	7.9%	0.89	1.6%	53.72	11.1%
	1980	4295.5	12.0%	1.28	3.7%	86.01	4.8%
All Size	1950	4.1		0.25		1.68	
Groups	1960	18.4	16.3%	1.26	17.7%	10.60	20.2%
	1970	33.7	6.2%	2.60	7.5%	47.72	16.2%
	1980	105.7	12.1%	4.61	5.9%	98.75	7.5%

[a]Includes only permanent cropland, temporary cropland, and cultivated pastures.

[b]Excludes administrators and their family members.

Notes: The table shows the total number of tractors per 1,000 establishments, per 1,000 hectares of cultivated land, and per 1,000 workers, by establishment size group. Tractors of all horsepower categories are included. Cultivated land includes only permanent cropland, temporary cropland, and cultivated pastures. Workers include only permanent and temporary employees, and sharecroppers and others. The growth rates are compound growth rates per year. Source: IBGE Agrarian Census.

by 1960, the use of land-saving inputs was still quite low on average. Less than 3% of the establishments below 10ha declared to have used chemical fertilizers, and this

proportion was similar among the establishments above 1,000ha. At 6-8%, the rate of adoption in the middle strata of 10-1,000ha was only marginally better.

The rate of adoption of chemical fertilizers improved across all strata during the 1960s. The highest rates of adoption were still concentrated in the middle strata, ranging from 15% to 20% in 1970. By 1980, in turn, over 30% of the establishments in these strata declared to use chemical fertilizers.

Table 3.8: Share of establishments using chemical fertilizers and lime, by area group (%)

	< 10 ha	10-100 ha	100-1,000 ha	1,000-10,000 ha	> 10,000 ha
			Chemical Fertilizers		
1950	–	–	–	–	–
1960	2.6	6.2	7.9	2.8	0.1
1970	7.1	19.4	15.3	14.9	6.5
1980	15.7	37.7	32.9	36.1	30.9
			Lime		
1950	–	–	–	–	–
1960	0.4	0.7	1.6	1.2	0.1
1970	0.6	2.3	3.2	5.4	2.8
1980	2.1	8.4	10.6	14.2	13.4

Notes: The table shows the share of establishments of each area group using chemical fertilizers, and the share of establishments of each area group using Lime. The area groups include establishments with a total area of less than 10 hectares (< 10 ha), of between 10 and 100 hectares (10-100 ha), of between 100 and 1000 hectares (100-1000 ha), of between 1,000 and 10,000 hectares (1,000-10,000 ha), and of more than 10,000 hectares (> 10,000 ha). Source: IBGE Agrarian Census.

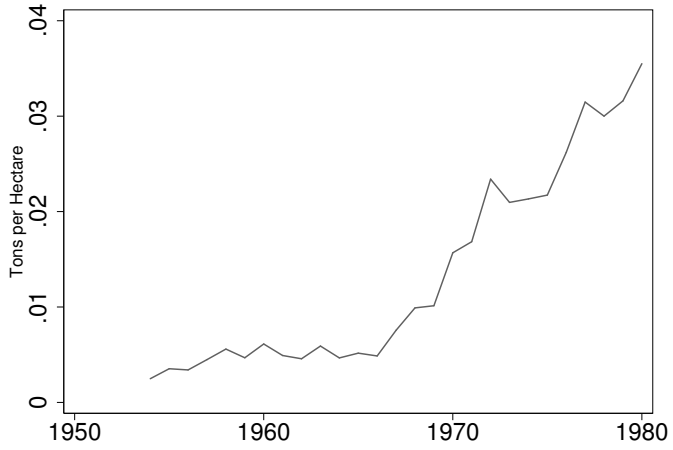
A similar, though less marked increase was verified in the case of the use of lime, with the larger establishments reporting the highest rates of adoption. Still, in 1980 the rates of adoption were never above 15% across establishment sizes, and only 2.1% among smallholders.

To build an approximate measure of fertilization per hectare, I linearly interpolated the census data on cultivated area and combined it with the annual apparent consumption of nitrogen, phosphate, and potassium (NPK) fertilizers, which is avail-

able starting in 1954. The linear interpolation of census data on cultivated area is a reasonable procedure, since only partial surveys on a per-crop (rather than per-establishment) basis exist for the years between census surveys.

The results are presented in Figure 3.5. As we can see, average fertilization per hectare remained stagnant during the 1950s and most of the 1960s. Only in 1967, coinciding with the sharp acceleration in subsidized credit, did the fertilization rate begin to increase at a fast pace.

Figure 3.5: Apparent consumption of chemical fertilizers by area of cultivated land (tons/ha)



Notes: This figure shows the ratio of apparent consumption of chemical fertilizers to total area of cultivated land. The apparent consumption of chemical fertilizers is defined as domestic production plus imports of nitrogen, phosphate, and potassium fertilizers. Cultivated land includes permanent cropland, temporary cropland, and cultivated pastures. The area of cultivated land between census years was calculated through linear interpolation. Sources: Ferreira and dos Anjos (1983) (for the apparent consumption of fertilizers), and IBGE Agrarian Census (for cultivated land).

3.5.2 Land Yields

The combination of policies and input choices described above gave rise to a relatively extensive pattern of output growth throughout the period — compared to yield increases, the expansion of cultivated area accounted for most of the output expansion recorded by the major crops (Graham et al., 1987).

Panel (a) in Figure 3.6 presents an aggregate measure of the average land yields for 17 major crops for which consistent time series exist for the 1950-1980 period.[10] To construct the measure, I first created indices of the physical yield measures for each crop (with 1952=100), and then computed an average weighted by the shares of each crop in the total harvested area for the group. I then converted the aggregate index to logarithmic scale in order to estimate linear growth models and apply the Bai-Perron test for structural breaks described in section 3.4.1. As before, the dashed lines show the fitted linear trend models, and the vertical lines indicate the estimated breakpoints, if any. The numbers above the dashed lines show the average growth rate of aggregate land yields in each sub-period (in % per year).

As shown in panel (a), despite considerable volatility (owing primarily to weather shocks), the trend growth rate of the aggregate land yield measure was quite slow in the 1950-1980 period: 0.4% per year. The average of the aggregate index during the 1975-1980 period was only 8.7% higher than the average for the 1950-1955 period. The Bai-Perron procedure did not identify any structural breaks in the series.

This general trend, however, masks considerable heterogeneity across crops. The sharpest differences occur between major export crops and domestic food crops. Panel (b) shows a similarly computed index including only the major export crops (coffee, cacao, cotton, oranges, soybeans, and sugarcane). The aggregate yield index displays a somewhat faster rate of growth for the 1950-1980 period: 0.68% per year, resulting in an average measure that was 17% higher in 1975-1980 compared to 1950-1955 (again, no structural breaks were identified).

Figure E.3 in the Appendix presents crop-specific yield measures for the six major export crops. Until the mid 1960s, the slow growth in the aggregate measure is due to the stagnant yields of coffee, in a context in which coffee still accounted for most of

[10]These crops include bananas, onions, peanuts, tomatoes, beans, cacao, cassava, coffee, corn, cotton, oranges, potatoes, rice, soybeans, sugarcane, sweet potatoes, and wheat.

the area cultivated with export crops. In the 1960s, the federal government adopted a coffee eradication program to combat overproduction and low world prices. At the same time, it sought to diversify the composition of agricultural exports, directing considerable efforts to the promotion of exports of processed goods utilizing oranges, soy, and sugarcane. These crops, along with cacao, recorded increases in both yields and cultivated area in the 1970s, helping to offset the trends of the traditionally dominant export crops: coffee (whose yields were stagnant) and cotton (whose yields declined in the 1960s and 1970s).

Panel (c) in figure 3.6 shows that the aggregate yield for domestically-oriented crops lagged behind that of export-oriented crops — in 1975-1980 they were only 4% higher than in 1950-1955. But this picture of slow but positive growth is primarily due to the effect of corn yields which, as seen in Figure E.4 in the Appendix, grew throughout the period. Indeed, panel (d) shows that, when corn (a crop utilized primarily by the processing and the livestock industries) is excluded, the aggregate yield of domestic food crops was stagnant until the mid 1970s, and declined sharply thereafter.

As seen in figure E.4, the decline in yields was driven primarily by staple foods in the diets of the Brazilian poor and working classes: rice, beans, and cassava. As noted by contemporaneous authors, the diversification of agricultural exports in the 1970s occurred concurrently with a decline in the per-capita output — and, in some cases, a decline in the absolute output — of domestic food crops (see, e.g. Barros and Graham, 1978). This decline resulted in a substantial increase in the relative price of domestically-traded food crops with respect to both export-oriented crops and domestic industrial goods (Homem de Melo, 1979).

The decline in yields of food crops in the 1970s has been traditionally linked to the expansion in the area dedicated to export crops and the resulting use of less fertile land for food production. The preceding analysis suggests that the insufficient

development of broad-based national research and extension programs also played a role. Indeed, figures E.3 and E.4 in the Appendix suggest that the crop-specific research programs described in section 3.4.2 — such as for cacao in the 1960s and 1970s, for cotton in the 1950s, and for corn since the early 1950s — appeared to have helped these crops to record yield increases during at least part of the period analyzed. Research and extension efforts for basic food crops were comparatively underdeveloped.

Despite the good performance of some crops, the aggregate record for Brazilian agriculture is one of low increase in land yields during the 1950-1980 period, a factor that, together with the marked increase in the mechanization of labor-intensive tasks, resulted in declining labor-land ratios among the most dynamic and commercially-oriented establishments, as described in section 3.3.

3.6 Conclusion

Despite displaying one of the world's fastest rates of industrialization during 1950-1980, the Brazilian economy failed to reduce rural and urban underemployment. Partly for that reason, outstanding growth in per capita income went hand in hand with persistent poverty indicators (Romão, 1991).

This paper contributed an explanation for the underemployment problem by examining labor displacement as a hallmark of agricultural modernization in the period. It examined how government policies to promote the use of modern inputs interacted with size and power inequality across landholdings to yield a marked labor-saving bias in technical change.

Even though price and credit policies did not explicitly discriminate in favor of labor-saving inputs, they disproportionately benefited large establishments. These establishments, however, were prone to impart a labor-saving bias in their input choices. The reasons for this bias are rooted in the structure of the latifundio-minifundio sys-

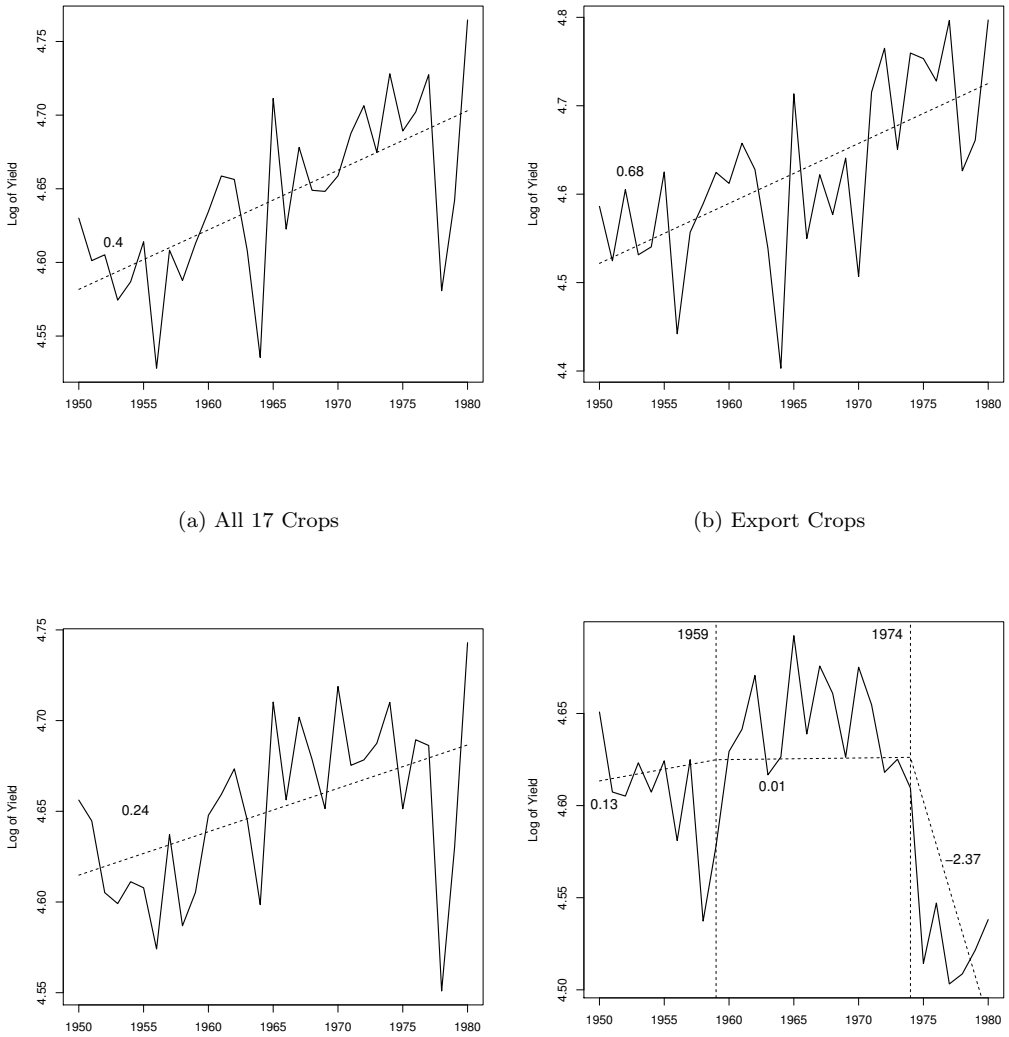
tem. First, external workers make up a greater share of the costs of large establishments. Second, large establishments face higher labor disciplining costs in a context of incomplete contracts. Third, large establishments benefit from control over land to derive monoposonistic power in local labor markets and political power in general.

In addition, public policies neglected key components of land-saving innovation packages that are subject to severe market failures, such as research and extension, rural education, and rural infrastructure. As a result of technical complementarity between these public goods and private land-saving inputs, the adoption of the latter was sluggish until the 1970s.

Since such market failures did not beset the development of mechanized techniques and their related capital inputs, the adoption of labor-saving innovations proceeded at a much faster pace. Moreover, as suggested by De Janvry (1978), since they did not upset the extensive pattern of land use of the large establishments, they faced no political resistance.

Encouraging improvements in the action of the state occurred in the 1970s, especially with respect to research and extension. Their benefits, however, were not reaped before the interruption of the industry-led growth process in the 1980s. This tardiness, along with the glaring absence of significant land reform throughout the 1950-1980 period, implied a missed opportunity with lasting consequences for the Brazilian economy and society.

Figure 3.6: Area-weighted yield indices (in logarithmic scale)



(a) All 17 Crops

(b) Export Crops

(c) Domestic Crops

(d) Domestic Crops (Excluding Corn)

Notes: The figures show the evolution of crop yield indices (in logarithmic scale). The indices are a weighted average of crop-specific indices of physical yield per hectare. The weights are the shares of each crop in the total harvested area of each of four groups: all 17 major crops (panel a), export-oriented crops (panel b), domestically-oriented crops (panel c), and domestically-oriented crops excluding corn (panel d). The crop-specific physical yields were computed as the ratio of annual output (in tons or other crop-specific units) divided by the harvested area (in hectares). The resulting values were then transformed into crop-specific index numbers, with 1952=100, prior to the weighting. The plots show the weighted indices in logrithmic scale. The solid lines show the logarithm of the weighted indices. The vertical lines indicate the years in which a structural break in the growth rate of the yield index was identified by the Bai-Perron procedure. The dashed lines show the linear models fit for each of the resulting subperiods (if any). The numbers near the dashed lines show the slope of the linear model, i.e. the average growth rate of the yield index in each sub-period (in % per year). The linear models and growth rates were estimated using the procedure in Boyce (1986a). The 17 crops in panel (a) include: bananas, onions, peanuts, tomatoes, beans, cacao, cassava, coffee, corn, cotton, oranges, potatoes, rice, soybeans, sugarcane, sweet potatoes, and wheat. The export crops in panel (b) include cacao, coffee, cotton, oranges, soybeans, and sugarcane; the remaining crops are considered domestic crops. Prior to 1959, physical yields for coffee were reported with reference to coffee beans, and from 1959 they were reported with reference to coffee berries. I converted the former series to the unit of the latter using the annual growth rates for 1951-1958. Source: IBGE Statistical Yearbook of Brazil, various years.

APPENDIX A

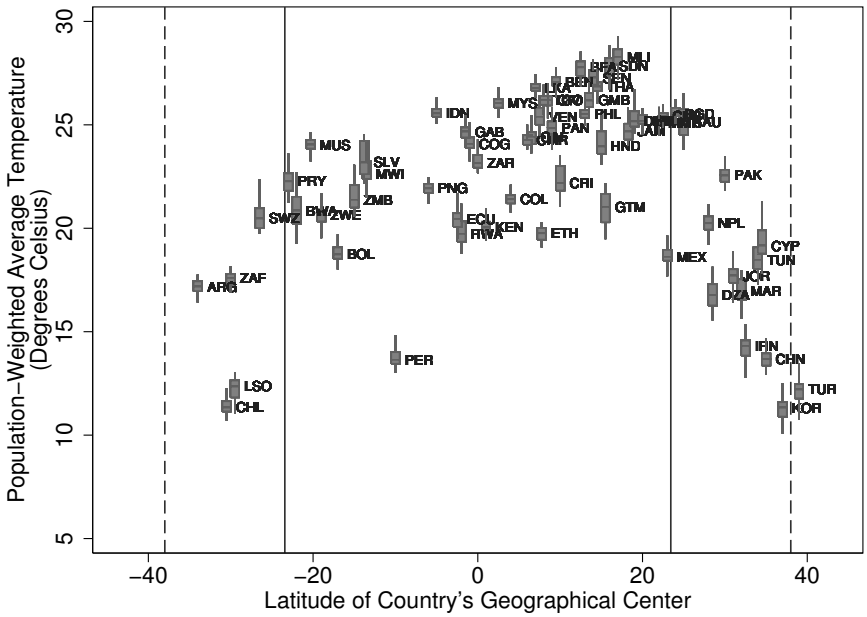
DESCRIPTIVE STATISTICS

Table A.1: Descriptive statistics of growth and temperature

	Mean	Standard Deviation			Countries
		Overall	Within	Between	
Growth in Agriculture (%/yr.)					
All Countries	2.67	8.62	8.54	1.22	62
Asia and Pacific Islands	3.01	4.78	4.74	0.69	13
Latin America and Caribbean	2.57	6.00	5.92	1.02	17
Sub-Saharan Africa	2.27	9.81	9.74	1.19	24
Middle East and North Africa	3.79	14.16	14.08	1.63	7
Growth in Manufacturing (%/yr.)					
All Countries	4.51	8.55	8.17	2.51	62
Asia and Pacific Islands	6.85	7.69	7.23	2.81	13
Latin America and Caribbean	3.29	6.74	6.58	1.53	17
Sub-Saharan Africa	3.68	10.30	10.04	2.28	24
Middle East and North Africa	5.78	7.60	7.49	1.36	7
Weighted Temperature (^{o}C/yr.)					
All Countries	21.83	4.48	0.49	4.48	62
Asia and Pacific Islands	22.76	4.90	0.34	5.00	13
Latin America and Caribbean	21.19	4.04	0.51	4.13	17
Sub-Saharan Africa	23.22	3.78	0.48	3.83	24
Middle East and North Africa	17.37	3.83	0.63	4.07	7

Notes: The decomposition of the overall standard deviation was obtained by using the following transformation: $\tilde{y}_{i,t} = y_{i,t} - \bar{y}_i + \bar{y}$. Where y denotes the variable of interest, i denotes countries, t denotes years, $\bar{y}_i$ denotes the average of y across time in country i, and $\bar{y}$ denotes the overall average of y. The within-country standard deviation is the standard deviation of $\tilde{y}_{i,t}$, while the between-country standard deviation is given by the standard deviation of $\bar{y}_i$ across all countries. For details about the data sources, see the Appendix.

Figure A.1: Latitude of country geographical centers and variability in population-weighted average temperature



Notes: The figure shows the variability of annual population-weighted average temperature in each country plotted against the latitude of the country's geographical center. Small adjustments (of up to .5 degree) were made when these latitudes (available without decimal places) overlapped. The length of the boxes show each country's interquartile range (iqr). The length of the vertical lines above the boxes is determined by the smallest value between a country's highest annual temperature and the top quartile temperature plus $1.5 \times iqr$. The length of the vertical lines below the boxes is determined by the smallest value between a country's lowest annual temperature and the bottom quartile temperature minus $1.5 \times iqr$. Outliers are not shown. The solid vertical lines indicate the latitude of the tropics of Cancer (23.43^o) and Capricorn (-23.43^o), and the dashed vertical lines indicate the latitude of the limits of the subtropical region (-38°, 38°). For details about the data sources, see Appendix B.

APPENDIX B

DATA SOURCES AND VARIABLE DEFINITIONS

List of Countries in the Baseline Sample: Algeria, Argentina, Bangladesh, Benin, Bolivia, Botswana, Burkina Faso, Cameroon, Central African Republic, Chile, China, Colombia, Congo (Dem. Rep.), Congo (Rep.), Costa Rica, Cote d'Ivoire, Cuba, Cyprus, Dominican Republic, Ecuador, El Salvador, Ethiopia, Gabon, The Gambia, Guatemala, Honduras, India, Indonesia, Iran, Jamaica, Jordan, Kenya, South Korea, Lesotho, Malawi, Malaysia, Mali, Mauritius, Mexico, Morocco, Myanmar, Nepal, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Rwanda, Saudi Arabia, Senegal, South Africa, Sri Lanka, Sudan, Swaziland, Thailand, Togo, Tunisia, Turkey, Venezuela, Zambia, Zimbabwe.

Table B.1: Data sources and variable definitions

	Source/Definition
General	
Sectoral real value added	WDI
Population-weighted average temperature	Dell et al. (2012a)
Table 1.1	
Set 1 : Stocks	
Human capital stock	PWT 8
PPP-adjusted GDP per capita (log)	PWT 8
Set 1 : Flows	
Real exchange rate undervaluation (log)	Rodrik (2008), calculated with data from PWT 8
External terms of trade (log)	PWT 8
Set 2: Stocks	
Polity II score	Marshall et al. (2013), updated.
Set 2: Flows	
Merchandise trade (% of GDP)	PWT 8
Real exchange rate volatility	PWT 8, defined as standard deviation over each period.
Gross capital formation (% of GDP)	PWT 8
Government consumption (% of GDP)	PWT 8
Table 1.4	
PPP-adjusted GDP per capita	PWT 8
Share of agriculture in GDP	WDI
Agricultural exports	FAO
Merchandise trade (% of GDP)	PWT 8
Table 1.5	
Civil conflict	Marshall (2013)
Hydropower production	WDI
Table 1.6	
Gross capital formation (% of GDP)	WDI
Gross saving (% of GDP)	WDI
Labor Productivity	PWT 8, defined as real GDP per person engaged
Agricultural exports	FAO
Food imports over merchandise imports	WDI
Merchandise trade (% of GDP)	PWT 8
Trade tax revenues (% of GDP)	Baunsgaard and Keen (2010)
Figure A.1	
Country geographical centers	NGA GEOnet Names Server

Note: WDI: World Development Indicators. PWT 8: Penn World Table version 8.0. FAO: Food and Agriculture Organization. NGA: National Geospatial-Intelligence Agency.

APPENDIX C

PROOFS OF PROPOSITIONS

C.1 The Impact of Technical Change on Income Distribution in the Dual Scenario

Assume a given distribution of land between the smallholding and the surplus-extracting subsectors. If total land is normalized to unity, total agricultural output is thus

$$A = \sigma_r t_r + \sigma_s(1 - t_r) \tag{C.1}$$

where the subscript r denotes the surplus-extracting sector, the subscript s denotes the smallholding sector, and t_i is the share of sector i in total land.

The rural product wage is set by the average output in the smallholding sector:

$$\omega_a = \frac{\sigma_s(1 - t_r)}{1 - l_m - l_r} \tag{C.2}$$

In turn,

$$l_r = \frac{\sigma_r t_r}{q_r} \tag{C.3}$$

where l_r is the share of the surplus-extracting sector in total employment, and l_m is the predetermined share of industrial sector in total employment.

Combining (C.2) and (C.3) with equation (2.3) yields a solution for β:

$$\beta = \frac{\sigma_s(1-t_r)}{1-l_m-\frac{\sigma_r t_r}{q_r}}\left(\frac{\sigma_s(1-t_r)+\sigma_r t_r}{1-l_m}\right)^{-1} \tag{C.4}$$

It is straightforward to see that labor-saving technical change (either uniform or taking place only in the surplus-extracting subsector) will unambiguously lower β. In turn, land-saving technical change will raise β if:

$$l_r > l_s \gamma \tau \tag{C.5}$$

where $0 < l_s < 1$ is the share of the smallholding subsector in the total labor force, and $0 < \gamma < 1$ is the share of the surplus-extracting subsector in total agricultural output (i.e. $\gamma = \frac{t_r \sigma_r}{A}$). Finally, if land-saving technical change takes place uniformly across both subsectors, $\tau = 1 - \frac{\sigma_r}{\sigma_s}$. The widely documented inverse size-yield relationship suggests strongly that $0 < \tau < 1$. In turn, if land-saving technical change takes place only in the surplus-extracting subsector, $\tau = 1$.

Thus, for plausible parameter values — which require that the surplus-extracting subsector be of a suitably (but reasonably) minimum size —, land-saving technical change will raise the sector-wide wage share in the dual scenario.

C.2 Proof of Proposition 2.2.1

Given the assumption of stability in the market for industrial goods, a necessary and sufficient condition for land-saving technical change to raise aggregate demand for industry is for it to cause a shortfall of *ex ante* saving with respect to investment. That is, using (2.13):

$$\frac{d[(1-\beta)\sigma_a p]}{d\sigma_a} < 0 \tag{C.6}$$

It follows from (2.12) that

$$\frac{dp}{d\sigma_a} = \frac{-1 + \eta\alpha(1+\theta)}{\sigma_a[\epsilon + \eta(1-\alpha)]}p \tag{C.7}$$

recall that $\eta > 0$ and $\epsilon > 0$ are the constant elasticities of income and substitution in the demand for agricultural goods, $0 < \alpha < 1$ is the share of rural workers in the total demand for agricultural goods, and $\theta \geq 0$ is the elasticity of the the wage share in agriculture with respect to an increase in σ_a.

Combining (C.6) and (C.7) yields equation (2.16) in proposition 2.2.1 (with $\theta = 0$ in the owner-cultivator scenario).

C.3 Proof of Proposition 2.2.2

Given the assumption of stability in the market for industrial goods, a necessary and sufficient condition for land-saving technical change to *lower* aggregate demand for industry is:

$$\frac{d[(1-\beta)\sigma_a p]}{dq_a} > 0 \tag{C.8}$$

From (2.12), it follows that

$$\frac{dp}{dq_a} = \frac{-\eta\alpha\frac{\phi}{q_a}}{\epsilon + \eta(1-\alpha)}p \tag{C.9}$$

Combining (C.9) and (C.8) gives:

$$\epsilon > \eta\left(\frac{\alpha - \beta}{\beta}\right) \tag{C.10}$$

Given that $\eta > 0$ and $\epsilon > 0$, the condition above will be trivially satisfied if $\alpha < \beta$. As shown in section 2.2.4, the initial assumption that rural wages are high enough to ensure positive consumption of industrial goods ensures that $\alpha < \beta$.

APPENDIX D

SHORT-RUN DYNAMICS

This section discusses the short-run dynamics of the warranted growth paths of both the demand-constrained and the saving-constrained regimes.

D.1 The demand-constrained regime in the short run

As in Nakatani and Skott (2007), I assume that in the short run both the rate of accumulation ($h = \frac{I}{K}$) and the output-capital ratios (σ_m) are predetermined, and not necessarily equal to their warranted-growth values — i.e. $h \neq g(\pi, \hat{p}_m)$, and $\sigma_m \neq \sigma_m^d$. Goods market equilibrium in the demand-constrained regime will thus be given by

$$\sigma_m \pi + \frac{1}{K_m}(1-\beta)\sigma_a p = h \tag{D.1}$$

with h and σ_m predetermined, equilibrium is brought about by endogenous changes in the profit share; for a given rate of anticipated inflation, the change in the profit share is accompanied by an increase in the rate of (unanticipated) inflation, according to the WBE schedule in (2.9). The profit share that emerges in the short run induces firms to revise their output expansion plans according to the growth function in equation (2.11), described in section 2.2.3.

In turn, firms' investment demand is specified in Harrodian fashion. Firms wish to operate with a desired level of capacity utilization, and they will step up the rate of accumulation whenever actual capacity utilization exceeds the desired level. The equation below describes their behavior.

$$\dot{h} = \lambda(\sigma_m - \sigma_m^d), \quad \lambda > 0 \tag{D.2}$$

For a given profit share, the rates of growth of output and the capital stock will most likely differ. As a result, the actual output-capital ratio will change as a result of changes in capital utilization, according to

$$\hat{\sigma}_m = \hat{M} - h \Leftrightarrow \dot{\sigma}_m = \sigma_m[g(\pi, \hat{p}_m) - h] \tag{D.3}$$

Equations (D.2) and (D.3) define a two-dimensional dynamic system for the accumulation rate and the output-capital ratio. In stationary equilibrium, industrial output and the industrial capital stock grow at the same rate, with the output-capital ratio remaining at the desired level. This warranted growth path was analyzed in section 2.2 above.

At the stationary equilibrium, the Jacobian matrix associated with the system comprised of equations (D.2) and (D.3) is given by

$$J = \begin{bmatrix} 0 & \lambda \\ \sigma_m^d \left[g_\pi \frac{\partial \pi}{\partial h} + g_{\hat{p}_m} \frac{\partial \hat{p}_m}{\partial h} - 1\right] & \sigma_m^d \left[g_\pi \frac{\partial \pi}{\partial \sigma_m} + g_{\hat{p}_m} \frac{\partial \hat{p}_m}{\partial \sigma_m}\right] \end{bmatrix} \tag{D.4}$$

The conditions for local stability are:

$$Tr(J) < 0 \Leftrightarrow \left(g_\pi + g_{\hat{p}_m} \frac{\partial \hat{p}_m}{\partial \pi}\right) \frac{\partial \pi}{\partial \sigma_m} < 0 \tag{D.5}$$

and

$$Det(J) > 0 \Leftrightarrow g_\pi \frac{\partial \pi}{\partial h} < 1 - g_{\hat{p}_m} \frac{\partial \hat{p}_m}{\partial h} \tag{D.6}$$

Starting with the second condition, note that from D.1 it follows that

$$\frac{d\pi}{dh} = \frac{1}{\left[\sigma_m^d + \frac{1}{K_m}(1-\beta)\sigma_a \frac{\partial p}{\partial \pi}\right]} \tag{D.7}$$

The denominator in (D.7) is the change in total saving elicited by an increase in the profit share. As shown momentarily, $\frac{d\pi}{dh} > 0$ is a corollary of the local stability of the stationary point (which requires that the saving rate not only increases with the profit share, but that it increases by more than output growth). If $\frac{d\pi}{dh} > 0$, it follows from the WBE schedule for given inflation expectations (eq. 2.9) that $\frac{\partial \hat{p}_m}{\partial h} > 0$. Under these conditions, and using the fact that $g_{\hat{p}_m} < 0$, equations (D.6) and (D.7) yield the following *sufficient condition* for a positive determinant:

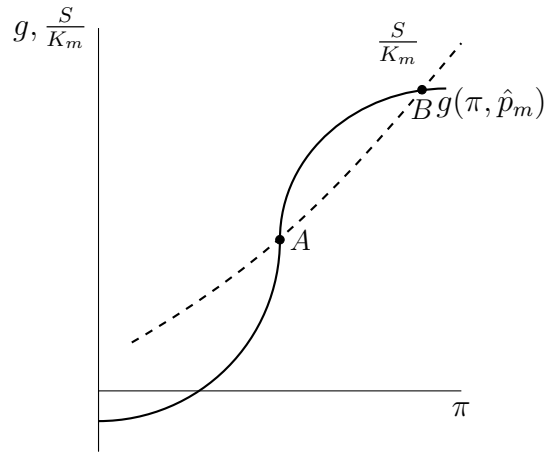
$$Det(J) > 0 \Leftarrow g_\pi < \sigma^d + \frac{1}{K_m}(1-\beta)\sigma_a \frac{\partial p}{\partial \pi} \tag{D.8}$$

The condition in (D.8) states that the saving function is steeper than the output growth function in the (π, g) space. Since $g_\pi > 0$, it also ensures that $\frac{d\pi}{dh} > 0$. Condition (D.8) is the correlate in the present setting of the well-known Robinsonian stability condition of post-Keynesian models, and it gives rise to the downward-sloping WG schedule described in section 2.2.3 (see equation 2.14). As argued in section 2.2.3, the existence of convex adjustment costs implies a non-linear output growth function, with a high sensitivity to the profit share at intermediate values, a low sensitivity at extreme values, and upper and lower bounds (see Skott, 1989, for further discussion). Figure D.1 below represents it as an S-shaped curve bounded from above and below. The case in which condition (D.8) is satisfied is shown at point B. For further discussion in a similar setting, see Nakatani and Skott (2007).

Now turn to the condition for a negative trace (equation D.5). From D.1 it follows that

$$\frac{d\pi}{d\sigma_m} = -\left[\frac{\pi + \frac{1}{K_m}(1-\beta)\sigma_a \frac{\partial p}{\partial \sigma_m}}{\sigma_m^d + \frac{1}{K_m}(1-\beta)\sigma_a \frac{\partial p}{\partial \pi}}\right] \tag{D.9}$$

Figure D.1: The saving-investment equilibrium with warranted growth.



Notes: The figure shows the saving-investment equilibrium in equation (2.13), which along with equation (2.12) ensures equilibrium in the market for both goods. The S-shaped curve depicts the non-linear output growth function $g(\pi, \hat{p}_m)$, which along the warranted growth path is equal to the rate of capital accumulation. The reasons for its non-linearity were discussed in section 2.2.3. The non-linear dashed schedule depicts a possible configuration of the economy-wide saving rate, $\frac{S}{K_m} = \sigma_m^d \pi + \frac{1}{K_m}(1-\beta)\sigma_a p$. As drawn, the figure allows for two equilibria with a non-negative industrial profit share. Point A is an unstable equilibrium which violates D.6, and point B is a stable equilibrium which satisfies D.6. The comparative statics carried out in section 2.2.4 assume the economy's warranted growth path satisfies the conditions for local stability (see Nakatani and Skott, 2007, for further discussion of multiple equilibria in a similar setting)

Condition (D.8) ensures that the term in brackets has a positive denominator. In turn, a sufficient condition for the term in brackets to have a positive numerator is that $\frac{\partial p}{\partial \sigma_m^d} \geq 0$. Totally differentiating equation (2.12) yields:

$$\frac{dp}{d\sigma_m} = \frac{(f^M - f^A)K_m p}{q_m \sigma_a[\eta(1-\alpha)+\epsilon]} \tag{D.10}$$

where f^M and f^A denote the per-worker demand for agricultural goods in the industrial and the agricultural sectors. As described in the paper, $\eta > 0$, $\epsilon > 0$, and $0 < \alpha < 1$. Since the urban wage premium is nonnegative (see equation 2.6) and preferences are identical across all types of workers, it follows that $f^M \geq f^A$ and $\frac{d\pi}{d\sigma_m} \leq 0$.

Using the fact that $\frac{d\pi}{d\sigma_m} \leq 0$ in equation (D.5) yields the following condition for a negative trace:

$$Tr(J) < 0 \Leftrightarrow g_\pi > -g_{\hat{p}_m} \frac{\partial \hat{p}_m}{\partial \pi} \tag{D.11}$$

which is condition (2.15) in the main text. As discussed in section 2.2.3, it will be satisfied if inflation is relatively low, in which case firms' output expansion plans will be fairly insensitive to increases in inflation. As argued in section 2.2.3, this situation is especially likely in a demand-constrained regime.

D.2 The saving-constrained regime in the short run

In the short run, anticipated inflation is also predetermined, and in general different from actual inflation. Unlike the demand-constrained regime, however, I now assume that actual inflation is above the threshold ($\hat{p^*}_m$), so that anticipated inflation will adjust to shortfalls with respect to actual inflation. The following equation describes this adaptive adjustment:

$$\dot{\hat{p}}^e_m = \psi(\hat{p}_m - \hat{p}^e_m) \tag{D.12}$$

where $\psi > 0$. The remainder of the model in the short run is as described in the previous section. Along with (D.2) and (D.3), equation (D.12) defines a three-dimensional dynamic system in the output-capital ratio, the rate of accumulation, and anticipated inflation. In equilibrium, there is warranted growth but at the rate compatible with the distributional norm in the industrial sector (so that inflation expectations are met).

The Jacobian matrix at the stationary point is given by

$$J = \begin{bmatrix} 0 & \lambda & 0 \\ \sigma^d_m \left[g_\pi \frac{\partial \pi}{\partial h} + g_{\hat{p}_m} \frac{\partial \hat{p}_m}{\partial h} - 1\right] & \sigma^d_m \left[g_\pi \frac{\partial \pi}{\partial \sigma_m} + g_{\hat{p}_m} \frac{\partial \hat{p}_m}{\partial \sigma_m}\right] & \sigma^d_m g_{\hat{p}_m} \\ \psi \frac{\partial \hat{p}_m}{\partial h} & \psi \frac{\partial \hat{p}_m}{\partial \sigma_m} & 0 \end{bmatrix} \tag{D.13}$$

And the associated Routh-Hurwitz conditions for local stability are:

1. $Tr(J) = \sigma_m^d \left[g_\pi \frac{\partial \pi}{\partial \sigma_m} + g_{\hat{p}_m} \frac{\partial \hat{p}_m}{\partial \sigma_m} \right] < 0$

2. $Det(J_1) + Det(J_2) + Det(J_3) = -\sigma_m^d g_{\hat{p}_m} \psi \frac{\partial \hat{p}_m}{\partial \sigma_m} - \lambda \sigma_m^d \left[g_\pi \frac{\partial \pi}{\partial h} + g_{\hat{p}_m} \frac{\partial \hat{p}_m}{\partial h} - 1 \right] > 0$

3. $Det(J) = \lambda \sigma_m^d \psi g_{\hat{p}_m} \frac{\partial \hat{p}_m}{\partial h} < 0$

4. $-Tr(J)[Det(J_1) + Det(J_2) + Det(J_3)] + Det(J) > 0$

Noting that $g_{\hat{p}_m} < 0$, we see that condition 3 is always satisfied. Satisfaction of condition 1 requires the same condition for a negative trace in the demand-constrained regime. In turn, condition 2 will be satisfied if

$$g_\pi \frac{\partial \pi}{\partial h} < 1 - g_{\hat{p}_m} \frac{\partial \hat{p}_m}{\partial h} - \frac{\psi}{\lambda} g_{\hat{p}_m} \frac{\partial \hat{p}_m}{\partial \sigma_m} \tag{D.14}$$

Since $\frac{\partial \hat{p}_m}{\partial \sigma_m} < 0$, condition (D.6) is necessary but not sufficient for condition (D.14) to be satisfied. Even if, as assumed throughout the paper, the more stringent condition (D.8) holds — which ensures $g_\pi \frac{\partial \pi}{\partial h} < 1$—, a sufficiently low suitably low speed of adjustment of anticipated inflation (ψ) relative to the speed of adjustment of accumulation (λ) may still be required.

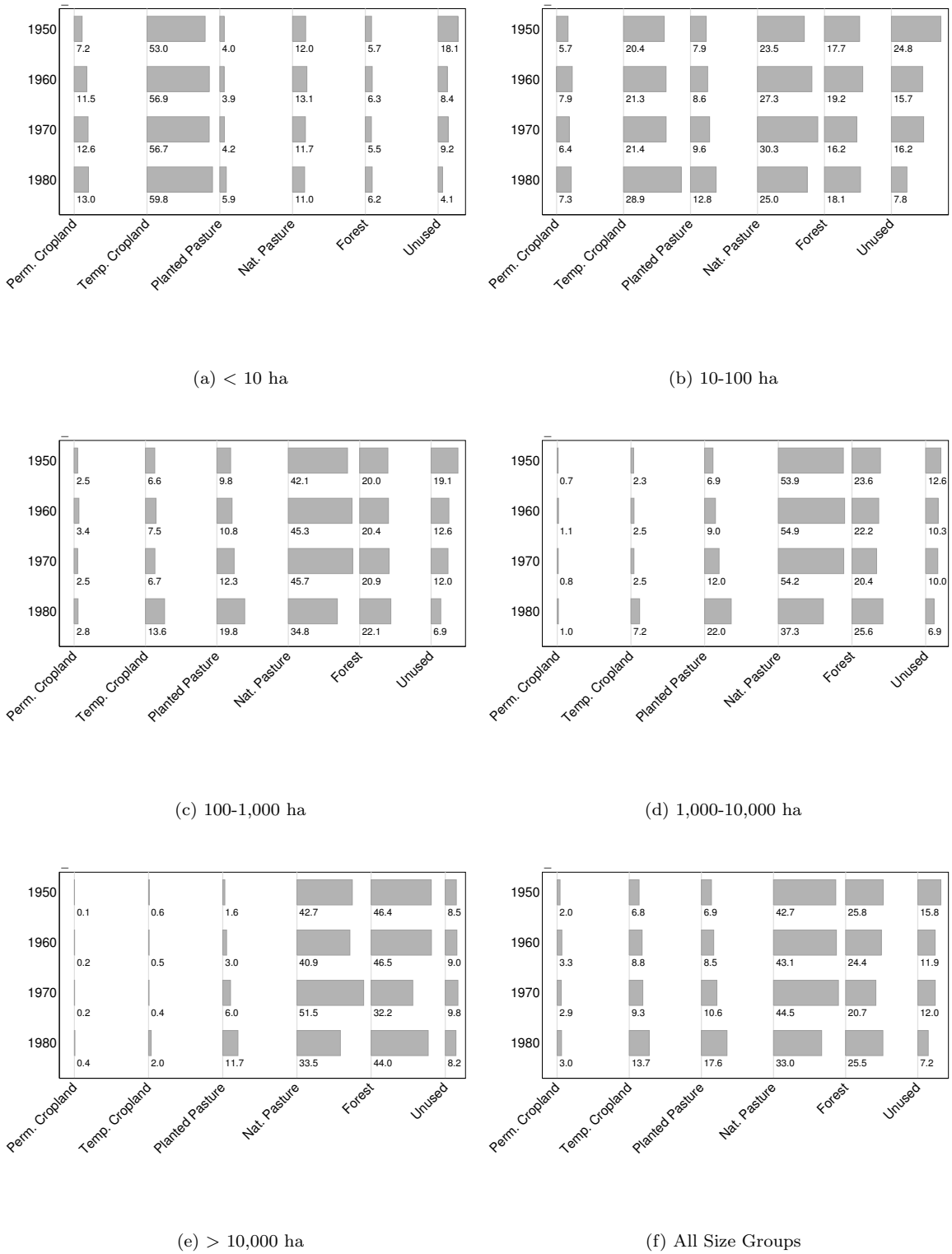
Finally, condition 4 above will be satisfied if the sum of principal minors is greater than the ratio of $Det(J)$ over $Tr(J)$. Again, a suitably low speed of adjustment of anticipated inflation (which would increase the sum of principal minors and reduce the absolute value of $Det(J)$) can ensure that the required inequality holds.

In sum, even though certain combinations of parameters may render the saving-constrained regime locally unstable, stability may well be attained.

APPENDIX E

ADDITIONAL FIGURES AND TABLES

Figure E.1: Land use by size group (in % of total land).



(a) < 10 ha

(b) 10-100 ha

(c) 100-1,000 ha

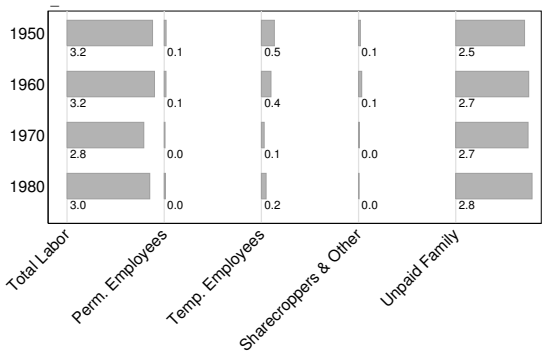
(d) 1,000-10,000 ha

(e) > 10,000 ha

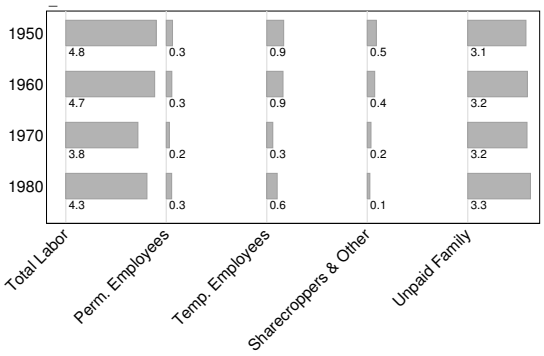
(f) All Size Groups

Notes: The figures show the ratio between total persons employed and total area of cropland and pastures, by establishment size group. Total employment includes unpaid family members, permanent employees, temporary employees, and sharecroppers and other arrangements. Total land includes permanent cropland, temporary cropland, natural pastures, and planted pastures. Source: IBGE Agrarian Census.

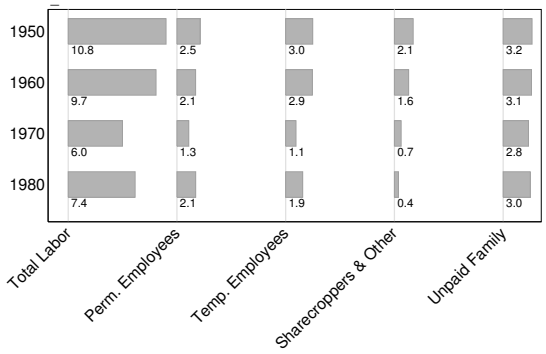
Figure E.2: Average number of workers per establishment, by size group (in persons per establishment).



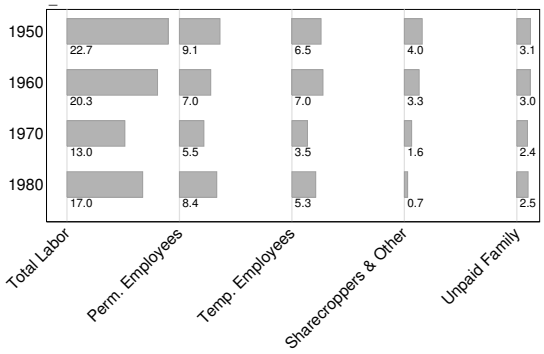
(a) < 10 ha



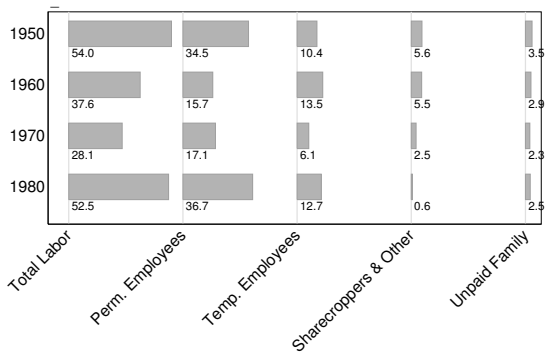
(b) 10-100 ha



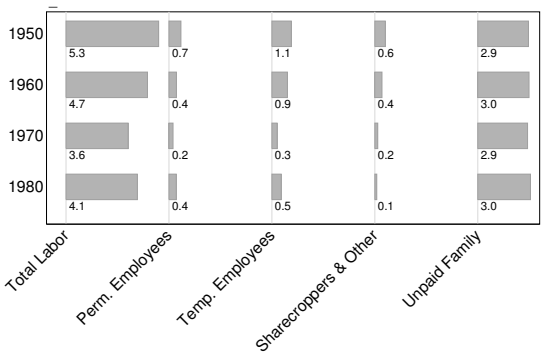
(c) 100-1,000 ha



(d) 1,000-10,000 ha



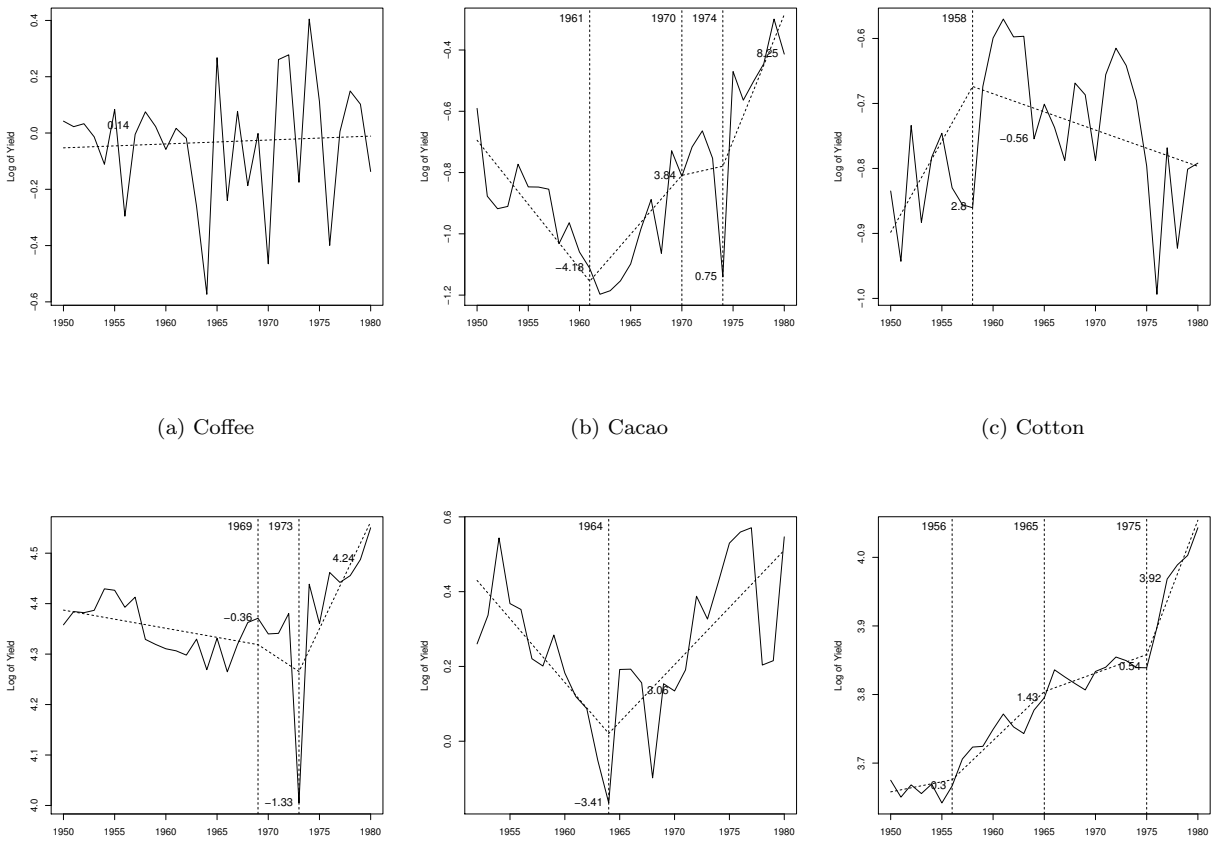
(e) > 10,000 ha



(f) All Size Groups

Notes: The figures show the ratio of employed workers per establishments, by establishment size group. The workers in each category include unpaid family members. Source: IBGE Agrarian Census.

Figure E.3: Land yields by export crop (in logarithmic scale).

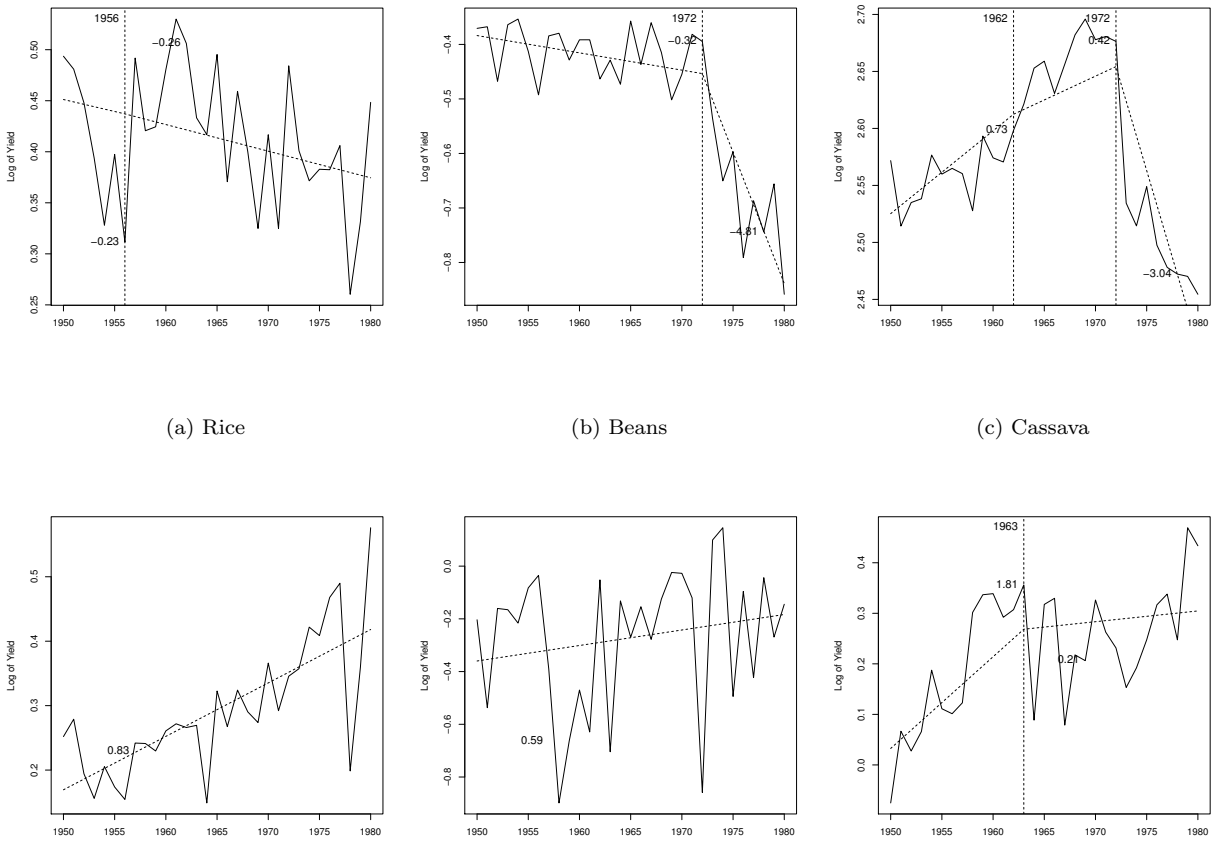


(a) Coffee (b) Cacao (c) Cotton

(d) Oranges (e) Soybeans (f) Sugarcane

Notes: The figures show the ratio between total persons employed and total area of cropland and pastures, by establishment size group. Total employment includes unpaid family members, permanent employees, temporary employees, and sharecroppers and other arrangements. Total land includes permanent cropland, temporary cropland, natural pastures, and planted pastures. Source: IBGE Agrarian Census.

Figure E.4: Land yields by domestic crop (in logarithmic scale).



(a) Rice (b) Beans (c) Cassava

(d) Corn (e) Wheat (f) Peanuts

Notes: The figures show the ratio between total persons employed and total area of cropland and pastures, by establishment size group. Total employment includes unpaid family members, permanent employees, temporary employees, and sharecroppers and other arrangements. Total land includes permanent cropland, temporary cropland, natural pastures, and planted pastures. Source: IBGE Agrarian Census.

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