The Role of the Structural Transformation in Aggregate Productivity[†]

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February 2009

Abstract

We investigate the role of sectoral differences in labor productivity in explaining the process of structural transformation – the secular reallocation of labor across sectors – and the time path of aggregate productivity across countries. Using a simple model of the structural transformation that is calibrated to the growth experience of the United States, we measure sectoral labor productivity differences across countries. Productivity differences between rich and poor countries are large in agriculture and services and smaller in manufacturing. Moreover, over time, productivity gaps have been substantially reduced in agriculture and industry but not nearly as much in services. In the model, these sectoral productivity patterns generate implications that are broadly consistent with the cross-country evidence on the structural transformation, aggregate productivity paths, and relative prices. We show that productivity catch-up in industry explains about 50 percent of the gains in aggregate productivity across countries, while low relative productivity in services and the lack of catch-up explains all the experiences of slowdown, stagnation, and decline observed across countries.

Keywords: labor productivity, structural transformation, sectoral productivity, employment, hours, cross-country data.
JEL Classification: O1,O4.

[†]We thank the editor and three referees for very useful and detailed comments. We also thank comments and suggestions from Tasso Adamopoulos, John Coleman, Mike Dotsey, Gary Hansen, Gueorgui Kambourov, Richard Rogerson, Marcelo Veracierto, Xiaodong Zhu, and audiences at ASU Economic Development Workshop, Inter-American Development Bank, Society for Economic Dynamics Meetings, University of Sydney, Winter Meetings of the Econometric Society, Wharton School, University of Pennsylvania, ITAM Summer Camp, Queen's University, and University of Rochester. Andrea Waddle provided excellent research assistance. All errors are our own. We gratefully acknowledge the support from the Connaught Fund at the University of Toronto (Duarte) and the Social Sciences and Humanities Research Council of Canada (Restuccia). *Contact Information:* Department of Economics, University of Toronto, 150 St. George Street, Toronto, ON M5S 3G7, Canada. E-mail: margarida.duarte@utoronto.ca; and diego.restuccia@utoronto.ca.

1 Introduction

It is a well-known observation that over the last 50 years countries have experienced remarkably different paths of economic performance.[1] Looking at the behavior of GDP per hour of individual countries relative to that of the United States we find experiences of sustained catch-up, catch-up followed by a slowdown, stagnation, and even decline (see Figure 1 for some illustrative examples).[2] Consider for instance the experience of Ireland. Between 1960 and 2004, GDP per hour in Ireland relative to that of the United States rose from about 35 percent to about 75 percent.[3] Spain also experienced a period of rapid catch-up to the United States from 1960 to around 1990, a period during which relative GDP per hour rose from about 35 to 80 percent. Around 1990, however, this process slowed-down dramatically and relative GDP per hour in Spain stagnated and later declined. Another remarkable growth experience is that of New Zealand where GDP per hour fell from about 70 to 60 percent of that of the United States between 1970 and 2004.

Along their modern path of development countries undergo a process of structural transformation by which labor is reallocated among agriculture, industry, and services. Over the last 50 years many countries have experienced substantial amounts of labor reallocation across sectors. For instance, from 1960 to 2004, the share of hours in agriculture in Spain fell from 44 to 6 percent while the share of hours in services rose from 25 to 64 percent. In about the same period, the share of hours in agriculture in Belgium fell just from 7 to 2 percent, while the share in services rose from 43 to 72 percent.

In this paper we study the behavior of GDP per hour over time from the perspective of sectoral productivity and the structural transformation.[4] Does a sectoral analysis contribute to the understanding of aggregate productivity paths? At a qualitative level, the answer to this question is clearly yes. Since aggregate labor productivity is the sum of labor

[1] See Chari, Kehoe, and McGrattan (1996), Jones (1997), Prescott (2002), Duarte and Restuccia (2006), among many others.

[2] We use GDP per hour as our measure of economic performance. Throughout the paper we refer to labor productivity, output per hour, and GDP per hour interchangeably.

[3] All numbers reported refer to trended data using the Hodrick-Prescott filter. See Section 2 for details.

[4] See Baumol (1967) for a discussion of the implications of structural change on aggregate productivity growth.

productivity across sectors weighted by the share of labor in each sector, the structural transformation matters for aggregate productivity. At a quantitative level the answer depends on whether there are substantial differences in sectoral labor productivity across countries. Our approach in this paper is to first develop a simple model of the structural transformation that is calibrated to the growth experience of the United States. We then use the model to measure sectoral labor productivity differences across countries at a point in time. These measures, together with data on sectoral labor productivity growth, imply time paths of sectoral labor productivity across countries. We use these measures of sectoral productivity in the model to assess their quantitative role on the structural transformation and aggregate productivity outcomes across countries.

We find that there are large and systematic differences in sectoral labor productivity across countries. In particular, differences in labor productivity levels between rich and poor countries are larger in agriculture and services than in manufacturing. Moreover, over time, productivity gaps have been substantially reduced in agriculture and industry but not nearly as much in services. To illustrate the implications of these sectoral differences for aggregate productivity, imagine that these productivity differences remain constant as countries undergo the structural transformation. Then as developing countries reallocate labor from agriculture to manufacturing, aggregate productivity can catch-up as labor is reallocated from a low relative productivity sector to a high relative productivity sector. Instead, countries further along the structural transformation can slowdown, stagnate, and decline as labor is reallocated from industry (a high relative productivity sector) to services (a low relative productivity sector). When the time series of sectoral productivity are fed into the model of the structural transformation, we find that high labor productivity growth in industry relative to that of the United States explains about 50 percent of the catch-up in relative aggregate productivity across countries. Although there is substantial catch-up in agricultural productivity, we show that this factor contributes little to aggregate productivity gains. In addition, we show that low relative productivity in services and the lack of catch-up explains all the experiences of slowdown, stagnation, and decline in relative aggregate productivity observed across countries.

We construct a panel data set on PPP-adjusted real output per hour and disaggregated output and hours worked for agriculture, industry, and services. Our panel data includes 29 countries with data covering the period from 1956 to 2004 for most countries.[5] From these data, we document three basic facts. First, countries follow a common process of structural transformation characterized by a declining share of hours in agriculture over time, an increasing share of hours in services, and a hump-shaped share of hours in industry. Second, there is substantial lag in the process of structural transformation for some countries and this lag is associated with the level of relative income. Third, there are sizable and systematic differences in sectoral growth rates of labor productivity across countries. In particular, most countries observe higher growth rates of labor productivity in agriculture and manufacturing compared to services. In addition, countries with high growth rates of aggregate productivity tend to have much higher productivity growth in agriculture and manufacturing than the United States, but this strong relative performance is not observed in services. Countries with low growth rates of aggregate labor productivity tend to observe low labor productivity growth in all sectors.

We develop a simple general equilibrium model of the structural transformation with three sectors − agriculture, industry, and services. Following Rogerson (2008), labor reallocation across sectors is driven by two channels: income effects due to non-homothetic preferences and substitution effects due to differential productivity growth across sectors.[6] We calibrate the model to the structural transformation of the United States between 1956 and 2004. A model of the structural transformation is essential for the purpose of this paper for two reasons. First, we use the calibrated model to measure sectoral productivity differences across countries at one point in time. This step is needed because of the lack of comparable (PPP-adjusted) sectoral output data across a large set of countries. Second, the process of structural transformation is endogenous to the level and changes over time in sectoral labor productivity. As a result, a quantitative assessment of the aggregate implications of sectoral

[5] Our sample does not include the poorest countries in the world: the labor productivity ratio between the richest and poorest countries in our data is only 10.

[6] For recent models of the structural transformation emphasizing non-homothetic preferences see Kongsamut, Rebelo, and Xie (2001) and emphasizing substitution effects see Ngai and Pissarides (2007).

productivity differences requires that changes in the distribution of labor across sectors be consistent with sectoral productivity paths.

The model implies that sectoral productivity levels in the first year in the sample tend to be lower in poor than in rich countries, particularly so in agriculture and services. Interestingly, the model implies low dispersion in productivity levels in manufacturing across countries. We argue that these differences in sectoral labor productivity implied by the model are consistent with the available evidence from studies using producer and micro data for specific sectors, for instance Baily and Solow (2001) for manufacturing and service sectors and Restuccia, Yang, and Zhu (2008) for agriculture. The levels of productivity implied by the model together with data on sectoral labor productivity growth for each country, imply time paths for sectoral productivity in each country. Given these time paths for productivity, the model reproduces the broad patterns of labor reallocation and aggregate productivity growth across countries. The model also has implications for sectoral output and relative prices that are broadly consistent with the cross-country data.

This paper is related to a large literature studying income differences across countries. Closely connected is the literature studying international income differences in the context of models with delay in the start of modern growth.[7] Since countries in our data set have started the process of structural transformation well before the first year in the sample period, our focus is on measuring sectoral productivity across countries at a point in time and on assessing the role of their movement over time in accounting for the patterns of structural transformation and aggregate productivity growth across countries.[8] Our paper is also closely related to a literature that emphasizes the sectoral composition of the economy in aggregate outcomes, for instance Restuccia, Yang, and Zhu (2008), Córdoba and Ripoll (2004), Vollrath (2009), Chanda and Dalgaard (2005), Coleman (2007), and Adamopoulos and Akyol (2007).[9] In studying labor productivity over time, our paper is related to a litera-

[7]See, for instance, Lucas (2000), Hansen and Prescott (2002), Ngai (2004), and Gollin, Parente, and Rogerson (2002).

[8]Herrendorf and Valentinyi (2006) also consider a model to measure sectoral productivity differences across countries but instead use expenditure data from the Penn World Table.

[9]See also Caselli and Tenreyro (2006) and the survey article by Caselli (2005).

ture studying country episodes of slowdown and depression.[10] Most of this literature focuses on the role of exogenous movements in aggregate total factor productivity and aggregate distortions on GDP relative to trend. We differ from this literature by emphasizing the importance of sectoral labor productivity on the structural transformation and the secular movements in relative GDP per hour across countries.

The paper is organized as follows. In the next section we document some facts about the process of structural transformation and sectoral labor productivity growth across countries. Section 3 describes the economic environment and calibrates a benchmark economy to U.S. data for the period between 1956 to 2004. In section 4 we discuss our quantitative experiment and perform counterfactual analysis. We conclude in section 5.

2 Some Facts

In this section, we document the process of structural transformation and labor productivity growth in agriculture, industry, and services for the countries in our data set at an annual frequency. Since we focus on long-run trends, data are trended using the Hodrick-Prescott filter with a smoothing parameter $\lambda = 100$. The appendix provides a detailed description of the data.

2.1 The Process of Structural Transformation

The reallocation of labor across sectors over time is typically referred to in the economic development literature as the process of structural transformation. This process has been extensively documented.[11] The structural transformation is characterized by a systematic fall in the share of labor allocated to agriculture over time, by a steady increase in the share of labor in services, and by a hump-shaped pattern for the share of labor in manufacturing. That is, the typical process of sectoral reallocation involves an increase in the share of labor in manufacturing in the early stages of the reallocation process, followed by a decrease in

[10] See Kehoe and Prescott (2002) and the references therein.
[11] See, for instance, Kuznets (1966), Maddison (1980), among others.

the later stages.[12]

We document the processes of structural transformation in our data set by focusing on the distribution of labor hours across sectors. We note, however, that this characterization is very similar to the one obtained by looking at shares of employment. Our panel data covers countries at very different stages in the process of structural transformation. For instance, our data includes countries that in 1960 allocated about 70 percent of their labor hours to agriculture (e.g., Turkey and Bolivia), as well as countries that in the same year have shares of hours in agriculture below 10 percent (e.g., the United Kingdom). Despite this diversity in the stage of structural transformation across the sample, all countries follow a common process of structural transformation. First, all countries exhibit declining shares of hours in agriculture, even the most advanced countries in this process, such as the United Kingdom and the United States. Second, countries at an early stage of the process of structural transformation exhibit a hump-shaped share of hours in industry, while this share is decreasing for countries at a more advanced stage. Finally, all countries exhibit an increasing share of hours in services. To illustrate these features, Figure 2 plots sectoral shares of hours for Greece, Ireland, Spain, and Canada.

The processes of structural transformation observed in our sample suggest two additional observations. First, the lag in the structural transformation observed across countries is systematically related to the level of development: poor countries are the ones with the highest shares of hours in agriculture, while rich countries are the ones with the lowest shares. (See for instance Gollin, Parente, and Rogerson (2007) and Restuccia, Yang, and Zhu (2008) for a detailed documentation of this fact for shares of employment across a wider range of countries.) Second, our data suggest the basic tendency for countries that start the process of structural transformation later to accomplish a given amount of labor reallocation faster than those countries that initiated this process earlier.[13]

[12]In this paper we refer to manufacturing and industry interchangeably. In the appendix we describe in detail our definition of sectors in the data.

[13]According to the U.S. Census Bureau (1975), Historical Statistics of the United States, the distribution of employment in the United States circa 1870 resembles that of Portugal in 1950. By 1948 the sectoral shares in the United States were 0.10, 0.34, and 0.56, levels that Portugal reached sometime during the 90's. Although Portugal is lagging behind the process of structural transformation in the United States, it

2.2 Sectoral Labor Productivity Growth

For the United States, the annualized growth rate of labor productivity between 1956 and 2004 has been highest in agriculture (3.8 percent), second in industry (2.4 percent), and lowest in services (1.3 percent).[14] This ranking of growth rates of labor productivity across sectors is observed in 23 out of the 29 countries in our sample and in all countries but Venezuela the growth rate in services is the smallest. Nevertheless, there is an enormous variation in sectoral labor productivity growth across countries.

Figure 3 plots the annualized growth rate of labor productivity in each sector against the annualized growth rate of aggregate labor productivity for all countries in our data set. The sectoral growth rate of the United States in each panel is identified by the horizontal dashed line while the vertical dashed line marks the growth rate of aggregate productivity of the United States. This figure documents the tendency for countries to feature higher growth rates of labor productivity in agriculture and manufacturing compared to services. For instance, in our panel, the average growth rates in agriculture and manufacturing are 4.0 and 3.1 percent while the average growth rate in services is 1.3 percent.

Figure 3 also illustrates that countries with low relative aggregate labor productivity growth tend to have low productivity growth in all sectors (e.g., Latin American countries) while countries with high relative aggregate labor productivity growth tend to have higher productivity growth than the United States in agriculture and, specially, industry (e.g., European countries, Japan, and Korea). For the countries that grew faster than the United States in aggregate productivity, labor productivity growth exceeded that of the United States, on average, by 1 percentage point in agriculture and 1.5 percentage points in industry. In contrast, labor productivity growth in services for these countries exceeded that of the United States, on average, by only 0.4 percentage points. The fact is that few countries have observed a much higher growth rate of labor productivity in services than the United

has accomplished about the same reallocation of labor across sectors in less than half the time (39 years as opposed to 89 years in the United States). See Duarte and Restuccia (2007) for a detailed documentation of these observations.

[14] The annualized percentage growth rate of variable x over the period t to $t+T$ is computed as $\left(\left(\frac{x_{t+T}}{x_t}\right)^{1/T} - 1\right) \times 100$.

States. These features of the data motivate some of the counterfactual exercises we perform in section 4.

3 Economic Environment

We develop a simple model of the structural transformation of an economy where at each date three goods are produced: agriculture, industry, and services. Following Rogerson (2008), labor reallocation across sectors is driven by two forces – an income effect due to non-homothetic preferences and a substitution effect due to differential productivity growth between industry and services. We calibrate a benchmark economy to U.S. data and show that this basic framework captures the salient features of the structural transformation in the United States from 1956 to 2004.

3.1 Description

Production At each date there are three goods produced: agriculture (a), manufacturing (m), and services (s) according to the following constant returns to scale production functions:

$$Y_i = A_i L_i, \qquad i \in \{a, m, s\}, \tag{1}$$

where Y_i is output in sector i, L_i is labor input in sector i, and A_i is a sector-specific technology parameter.[15] When mapping the model to data we associate the labor input L_i with hours allocated to sector i.

We assume that there is a continuum of homogeneous firms in each sector that are competitive in goods and factor markets. At each date, given the price of good-i output p_i

[15] We note that labor productivity in each sector is summarized in the model by the productivity parameter A_i. There are many features that can explain differences over time and across countries in labor productivity such as capital intensity and factor endowments. Accounting for these sources can provide a better understanding of labor productivity facts. Our analysis abstracts from the sources driving labor productivity observations.

and wages w, a representative firm in sector i solves:

$$\max_{L_i \geq 0} \{p_i A_i L_i - wL_i\}. \tag{2}$$

Households The economy is populated by an infinitely-lived representative household of constant size. Without loss of generality we normalize the population size to one. The household is endowed with L units of time each period which are supplied inelastically to the market. We associate L with total hours per capita in the data. The household has preferences over consumption goods as follows:

$$\sum_{t=0}^{\infty} \beta^t u(c_{a,t}, c_t), \quad \beta \in (0,1),$$

where $c_{a,t}$ is the consumption of agricultural goods at date t and c_t is the consumption of a composite of manufacturing and service goods at date t. The per-period utility is given by:

$$u(c_{a,t}, c_t) = a \log(a_t - \bar{a}) + (1-a)\log(c_t), \quad a \in [0,1],$$

where $\bar{a} > 0$ is a subsistence level of agricultural goods below which the household cannot survive. This feature of preferences has a long tradition in the development literature and it has been emphasized as a quantitatively important feature leading to the movement of labor away from agriculture in the process of structural transformation.[16]

The composite non-agricultural consumption good c_t is given by:

$$c_t = \left[b c_{m,t}^{\rho} + (1-b)(c_{s,t} + \bar{s})^{\rho} \right]^{\frac{1}{\rho}},$$

where $\bar{s} > 0$, $b \in (0,1)$, and $\rho < 1$. Given $\bar{s}$, these preferences imply that the income elasticity of service goods is greater than one. We note that $\bar{s}$ works as a negative subsistence consumption – when the income of the household is low, less resources are allocated to

[16]See, for instance, Echevarria (1997), Laitner (2000), Kongsamut, Rebelo, and Xie (2001), Caselli and Coleman (2001), Gollin, Parente, and Rogerson (2002), and Restuccia, Yang, and Zhu (2008).

the production of services and when the income of the household increases resources are reallocated to services. The parameter $\bar{s}$ can also be interpreted as a constant level of production of service goods at home. Our approach to modeling the home sector for services is reduced form. Rogerson (2008) considers a generalization of this feature where people can allocate time to market and non-market production of service goods. However, we argue that our simplification is not as restrictive as it may first appear since we abstract from the allocation of time between market and non-market activities. Our focus is on the determination of aggregate productivity from the allocation of time across market sectors.

Since we abstract from inter-temporal decisions the problem of the household is effectively a sequence of static problems.[17] At each date and given prices, the household chooses consumption of each good to maximize the per-period utility subject to the budget constraint. Formally,

$$\max_{c_i \geq 0} \left\{ a \log(c_a - \bar{a}) + (1-a)\frac{1}{\rho} \log \left[b c_m^{\rho} + (1-b)(c_s + \bar{s})^{\rho} \right] \right\}, \tag{3}$$

subject to

$$p_a c_a + p_m c_m + p_s c_s = wL.$$

Market Clearing The demand for labor from firms must equal the exogenous supply of labor by households at every date:

$$L_a + L_m + L_s = L. \tag{4}$$

Also, at each date, the market for each good produced must clear:

$$c_a = Y_a, \quad c_m = Y_m, \quad c_s = Y_s. \tag{5}$$

[17] Because we are abstracting from inter-temporal decisions such as investment our analysis is not crucially affected by alternative stochastic assumptions on the time path for labor productivity.

3.2 Equilibrium

A *competitive equilibrium* is a set of prices $\{p_a, p_m, p_s\}$, allocations $\{c_a, c_m, c_s\}$ for the household, and allocations $\{L_a, L_m, L_s\}$ for firms such that: (*i*) Given prices, firm's allocations $\{L_a, L_m, L_s\}$ solve the firm's problem in (2), (*ii*) Given prices, household's allocations $\{c_a, c_m, c_s\}$ solve the household's problem in (3), and (*iii*) Markets clear: equations (4) and (5) hold.

The first order condition from the firm's problem implies that the benefit and cost of a marginal unit of labor must be equal. Normalizing the wage rate to one, this condition implies that prices of goods are inversely related to productivity:

$$p_i = \frac{1}{A_i}. \tag{6}$$

The first order conditions for consumption imply that the labor input in agriculture is given by:

$$L_a = (1-a)\frac{\bar{a}}{A_a} + a\left(L + \frac{\bar{s}}{A_s}\right). \tag{7}$$

When $a = 0$, the household consumes $\bar{a}$ of agricultural goods and labor allocation in agriculture depends only on the level of labor productivity in that sector. When productivity in agriculture increases, labor moves away from the agricultural sector. Such restriction on preferences implies that output and consumption per capita of agricultural goods are constant over time, implications that are at odds with data. When $a > 0$ and productivity growth is positive in all sectors, the share of labor allocated to agriculture converges asymptotically to a and the non-homothetic terms in preferences become asymptotically irrelevant in the determination of the allocation of labor. In this case, output and consumption per capita of agricultural goods grow at the rate of labor productivity.

The first-order conditions for consumption of manufacturing and service goods imply:

$$\frac{b}{(1-b)}\left(\frac{c_m}{c_s + \bar{s}}\right)^{\rho-1} = \frac{p_m}{p_s}.$$

This equation can be re-written as:

$$L_m = \frac{(L - L_a) + \frac{\bar{s}}{A_s}}{1 + x}, \tag{8}$$

where

$$x \equiv \left(\frac{b}{1-b}\right)^{\frac{1}{\rho-1}} \left(\frac{A_m}{A_s}\right)^{\frac{\rho}{\rho-1}},$$

and L_a is given by (7).[18] Equation (8) reflects the two forces that drive labor reallocation between manufacturing and services in the model. First, suppose that preferences are homothetic (i.e., $\bar{s} = 0$). In this case, $L_s/L_m = x$ and differential productivity growth in manufacturing relative to services is the only source of labor reallocation between these sectors (through movements in x) as long as ρ is not equal to zero. In particular, when $\bar{s} = 0$, the model can be consistent with the observed labor reallocation from manufacturing into services as labor productivity grows in the manufacturing sector relative to services if the elasticity of substitution between these goods is low ($\rho < 0$). Second, suppose that $\bar{s} > 0$ (i.e., preferences are non-homothetic) and that labor productivity grows at the same rate in manufacturing and services or that $\rho = 0$ (i.e., x is constant). In this case, for a given L_a, productivity improvements lead to the reallocation of labor from manufacturing into services (services are more income-elastic). The model allows both channels to be operating during the structural transformation.

We note that the model abstracts from frictions to labor reallocation in agriculture by assuming perfect mobility across sectors. Changes to the extent of labor mobility in agriculture over time are thought to be important for the structural transformation and the movement of relative prices. For the purpose of our exercise what is critical is whether frictions affect labor reallocation in agriculture. For the group of countries and time period in our sample – which does not include the poorest countries in the world – there is an almost one-to-one

[18]When the growth rates of sectoral labor productivity are positive, the model implies that, in the long run, the share of hours in manufacturing and services asymptote to constants that depend on preference parameters a, b, ρ, and any permanent level difference in labor productivity between manufacturing and services. If productivity growth in manufacturing is higher than in services, then the share of hours in manufacturing asymptotes to 0 and the share of hours in services to $(1 - a)$.

relationship between changes in labor productivity and labor reallocation in agriculture both across time and countries. And this relationship is virtually identical across levels of development. Therefore, we argue that in our sample labor productivity plays a dominant role in determining labor allocation in agriculture and, as a result, this motivates our abstraction from frictions to labor mobility in the analysis. Moreover, in section 4 we show that the model is able to broadly reproduce the cross-country patterns of labor reallocation across sectors as well as the changes in relative prices in the data.[19]

3.3 Calibration

We calibrate a benchmark economy to U.S. data for the period from 1956 to 2004. Our calibration strategy involves selecting parameter values so that the equilibrium of the model matches the salient features of the structural transformation for the United States during this period. We assume that a period in the model is one year. We need to select parameters values for a, b, ρ, $\bar{a}$, $\bar{s}$, and the time series of productivity for each sector $A_{i,t}$ for t from 1956 to 2004 and $i \in \{a, m, s\}$.

We proceed as follows. First, we normalize productivity levels across sectors to one in 1956, i.e., $A_{i,1956} = 1$ for all $i \in \{a, m, s\}$. Then we use data on sectoral labor productivity growth in the United States to obtain the time paths of sectoral productivity. In particular, denoting $\gamma_{i,t}$ the growth rate of labor productivity in sector i at date t, we obtain the time path of labor productivity in each sector as $A_{i,t+1} = (1 + \gamma_{i,t})A_{i,t}$. Second, with positive productivity growth in each sector, the share of hours in agriculture in the long-run is given by a. Since the share of hours in agriculture has been falling systematically and was about 3 percent in 2004, we assume a long-run share of 1 percent. Although this target is somewhat arbitrary, our main results are not sensitive to this choice. Third, given values for ρ and b, $\bar{a}$ and $\bar{s}$ are chosen to match the shares of hours in agriculture and manufacturing in the United States in 1956 using equations (7) and (8). Finally, b and ρ are jointly chosen to match the share of hours in manufacturing over time and the annualized growth rate

[19] Distortions or frictions to labor mobility may help the model in explaining some specific country experiences but we leave these interesting explorations for future research.

of aggregate productivity. The annualized growth rate in labor productivity in the United States between 1956 and 2004 is roughly 2 percent. Table 1 summarizes the calibrated parameters and targets.

The shares of hours implied by the model are reported in Figure 4 (dotted lines), together with data on the shares of hours in the United States (solid lines). The equilibrium allocation of hours across sectors in the model matches closely the process of structural transformation in the United States during the calibrated period. The model implies a fall in the share of hours in manufacturing from about 39 percent in 1956 to 24 percent in 2004, while the share of hours in services increases from about 49 to 73 percent during this period.[20] Notice that even though the calibration only targets the share of hours in agriculture in 1956 (13 percent), the model implies a time path for the equilibrium share of hours in agriculture that is remarkably close to the data, declining to about 3 percent in 2004.

The model also has implications for sectoral output and for relative prices. Because sectoral output is given by labor productivity times the labor input and the model matches closely the time path of sectoral labor allocation for the U.S. economy, the output implications of the model over time for the United States are very close to the data. In particular, the model implies that output growth in agriculture is 2.08 percent per year (versus 2.29 in the data), while output growth in manufacturing and services in the model are 2.74 and 3.60 percent (versus 2.70 and 3.61 in the data). The model implies that the producer price of good i relative to good i' is given by the ratio of labor productivity in these sectors:

$$\frac{p_i}{p_{i'}} = \frac{A_{i'}}{A_i}. \tag{9}$$

We assess the price implications of the model against data on sectoral relative prices.[21] The model implies that the relative producer price of services to industry increases by 0.94 percent per year between 1971 and 2004, very close to the increase in the data for the relative price

[20] We emphasize that the model can deliver a hump-shaped pattern for labor in manufacturing for less developed economies even though during the calibrated period the U.S. economy is already in the second stage of the structural transformation whereby labor is being reallocated away from manufacturing.

[21] Data for sectoral relative prices is available from 1971 to 2004. See the appendix for details.

of services from the implicit price deflators (0.87 percent per year). The price of agriculture to manufacturing declines in the model at a rate of 1.04 percent per year from 1971 to 2004. This fall in the relative price of agriculture is consistent with data although the relative price of agriculture falls somewhat more in the data than in the model (3.12 percent per year).[22] Since productivity growth across sectors is the driving force of labor reallocation in the model, it is reassuring that this mechanism generates implications that are broadly consistent with the data. For this reason, we also discuss in Section 4 the relative price implications of the model when assessing the relevance of sectoral productivity growth for labor reallocation in the cross-country data.

4 Quantitative Analysis

In this section, we assess the quantitative role of sectoral labor productivity on the structural transformation and aggregate productivity outcomes across countries. In this analysis, we maintain preference parameters as in the benchmark economy and proceed in three steps. First, we use the model to restrict the level of sectoral labor productivity in the first period for each country. Second, using these levels and data on sectoral labor productivity growth in each country as the exogenous time-varying factors, the model implies time paths for the allocation of hours across sectors and aggregate labor productivity for each country. We then assess the cross-country implications of the model for labor reallocation across sectors, aggregate productivity, and relative prices. Third, we perform counterfactual exercises to illustrate the quantitative importance of sectoral analysis in explaining aggregate productivity experiences across countries.

[22] We note that in the context of our model distortions to the price of agriculture would not affect substantially the equilibrium allocation of labor in agriculture since this is mainly determined by labor productivity in agriculture relative to the subsistence constraint (since a is close to zero in the calibration). In this context, it would be possible to introduce price distortions to match the faster decline in the relative price of agriculture in the data without affecting our main quantitative results.

4.1 Relative Sectoral Productivity Levels

We use the model to restrict the levels of labor productivity in agriculture, industry, and services relative to those in the United States for the first year in the sample for each country. This step is needed because of the lack of comparable (PPP-adjusted) sectoral output data across a large set of countries. Since our data on sectoral value added are in constant local currency units some adjustment is needed. Using market exchange rates would be problematic for arguments well discussed in the literature, e.g. Summers and Heston (1991). Another approach would be to use the national currency shares of value added applied to the PPP-adjusted measure of real aggregate output from Penn World Tables (PWT). This is problematic because it assumes that the same PPP-conversion factor for aggregate output applies to all sectors in that country, while there is strong evidence that the PPP-conversion factors differ systematically across sectors in development.[23] Using detailed categories from the International Comparisons Program (ICP) Benchmark data in the PWT would also be problematic for inferences at the sector level since these data are based on the expenditure side of national accounts. For instance, it would not be advisable to use food expenditures and its PPP-conversion factor to adjust units of agricultural output across countries since expenditures on food include charges for goods and services not directly related to agricultural production.

Our approach is to use the model to back-out sector-specific PPP-conversion factors across countries and to use the constant-price value added in local currency units to calculate growth rates of labor productivity in each sector for each country. In particular, we use the model to restrict productivity levels in the initial period and use the data on growth rates of labor productivity to construct the time series for productivity that we feed into the model. This approach of using growth rates in constant domestic prices as a measure of changes in "quantities" is similar to the approach followed in the construction of panel data of comparable output across countries such as the PWT.[24]

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[23] See for instance the evidence on agriculture relative to non-agriculture in Restuccia, Yang, and Zhu (2008).

[24] In particular, in the PWT, the growth rates of expenditure categories such as consumption and investment are the growth rates of constant domestic price expenditures from national accounts.

We proceed as follows. For each country j, we choose the three labor productivity levels A_a^j, A_m^j, and A_s^j to match 3 targets from the data in the first year in the sample: (1) the share of hours in agriculture, (2) the share of hours in manufacturing (therefore the model matches the share of hours in services by labor market clearing), and (3) aggregate labor productivity relative to that of the United States.[25]

Figure 5 plots the average level of sectoral labor productivity relative to the level of the United States for countries in each quintile of aggregate productivity in the first year. The model implies that relative sectoral productivity in the first year tends to be lower in poorer countries than in richer countries, but particularly so in agriculture and services. In fact, the model implies that the dispersion of relative productivity in agriculture and services is much larger than in manufacturing. In the first year, the 6 poorest countries have relative productivity in agriculture and services around 20 and 10 percent while the 6 richest countries have relative productivity in these sectors around 86 and 84 percent. In contrast, for manufacturing, average relative productivity of the 6 poorest countries in the first year is 31 percent and that of the 6 richest countries is 70 percent.

The levels of sectoral labor productivity implied by the model for the first year together with observed growth rates of sectoral labor productivity imply time paths for sectoral productivity for each country. In particular, letting $\gamma_{i,t}^j$ denote the growth rate of labor productivity in country j, sector i, at date t, we obtain sectoral productivity as $A_{i,t+1}^j = (1+\gamma_{i,t}^j)A_{i,t}^j$. Figure 6 plots the average level of sectoral labor productivity relative to the level in the United States in the first and last years for countries in each quintile of aggregate productivity in the first year. We note that, on average, countries have experienced substantial gains in productivity in agriculture and industry relative to the United States (from a relative productivity level of 48 and 51 percent in the first period to 71 and 75 percent in the last period). In sharp contrast, countries experienced, on average, much smaller gains in productivity in services relative to the United States (from a relative productivity level

[25] We adjust $\bar{s}$ by the level of relative productivity in services in the first period for each country so that $\bar{s}/A_s$ is constant across countries in the first period of the sample. Although not modeled explicitly, one interpretation of $\bar{s}$ is as service goods produced at home. Therefore, $\bar{s}$ cannot be invariant to large changes in productivity levels in services.

of 46 percent to 49 percent). These features are particularly pronounced for countries in the top 3 quintiles of the productivity distribution. For these countries, average relative labor productivity in agriculture and industry increased from 66 and 59 percent to 100 and 85 percent, while average productivity in services increased from 63 to only 66 percent. We emphasize that the relative low levels of productivity in services in the first period together with the lack of catch-up over time imply that, for most countries, relative productivity levels in services are much smaller than those of agriculture and industry at the end of the sample period. Therefore, as these economies allocate an increasing share of hours to services, low relative labor productivity in this sector dampens aggregate productivity growth. These relative productivity patterns are suggestive of the results we discuss in subsection 4.3 where we show that productivity catch-up in industry explains a large portion of the gains in aggregate productivity across countries. In addition we show that low relative productivity levels in services and the lack of catch-up plays a quantitative important role in explaining the growth episodes of slowdown, stagnation, and decline across countries.

We argue that our productivity-level results are consistent with the available evidence from studies using producer and micro data. Empirical studies provide internationally-comparable measures of labor productivity for some sectors and some countries. These studies typically provide estimates for narrow sectoral definitions at a given point in time. One such study for agriculture is from the Food and Agriculture Organization (FAO) of the United Nations. This study uses producer data (prices of detailed categories at the farm gate) to calculate international prices and comparable measures of output in agriculture using a procedure similar to that of Summers and Heston (1991) for the construction of the PWT. We find that the labor productivity differences in agriculture implied by the model are qualitatively consistent with the differences in GDP per worker in agriculture between rich and poor countries from FAO for 1985.[26] Baily and Solow (2001) have compiled a wealth of case studies from the McKinsey Global Institute (MGI) documenting labor productivity differences in some sectors and countries. Their findings are broadly consistent with our

[26]See Restuccia, Yang, and Zhu (2008) for a detailed documentation of the cross-country differences in labor productivity in agriculture.

results. In particular, Baily and Solow emphasize a pattern that emerges from the micro studies where productivity differences in services are not only large but also larger than the differences for manufacturing across countries. The Organization for Economic Cooperation and Development (OECD) and MGI provide studies at different levels of sectoral disaggregation for manufacturing. These studies report relative productivity for a relatively small set of countries and most studies report estimates only at one point in time. One exception is Pilat (1996). This study reports relative labor productivity levels in manufacturing for 1960, 1973, 1985, and 1995 for 13 countries. While the implied relative labor productivity levels in industry in our model tend to be higher than those reported in this study, the patterns of relative productivity are consistent for most countries. Finally, consistent with our findings, several studies report that the United States has higher levels of labor productivity in service sectors than other developed countries and that lower labor productivity in service sectors compared to manufacturing is pervasive.[27]

4.2 The Structural Transformation across Countries

Given growth rates of sectoral labor productivity, the model has time-series implications for the allocation of labor hours and output across sectors, aggregate labor productivity, and relative prices for each country. In this section we evaluate these time-series implications of the model against the available cross-country data.

Overall, the model reproduces the salient features of the structural transformation and aggregate productivity across countries. To illustrate this performance, Figures 7 and 8 focus on the allocation of hours across sectors and relative aggregate productivity. Figure 7 reports the shares of hours across sectors and relative aggregate productivity in the last period of the sample for each country in the model and the data. Figure 8 reports the change between the last and first period in these variables (in percentage points) for the model and the data. As these figures illustrate, the model replicates well the patterns of the

[27]Baily, Farrell, and Remes (2005) for instance estimate that relative to the United States, with the exception of mobile telecommunications, France and Germany had lower relative productivity levels in 2000 and had lower growth rates of labor productivity between 1992 and 2000 for a set of narrowly-defined service sectors.

allocation of hours across sectors and relative aggregate productivity observed in the data, particularly so for the share of hours in agriculture and relative aggregate productivity. This performance attests to the ability of the model in replicating the basic trends observed for the share of hours in agriculture across a large cross-section of countries. Regarding the share of hours in industry, the model tends to imply a smaller increase over time compared to the data, particularly so for less developed economies where the share of hours in industry increased over the sample period. Conversely, the model tends to imply a bigger increase in the share of hours in services over the sample period than that observed in the data. This implication of the model suggests that, specially for some less developed countries, distortions to labor reallocation between industry and services may be important in accounting for their structural transformation.[28] As a summary statistic of the performance of the model in replicating the time-series properties of the data, we compute the average absolute deviation (over time and across countries) in percentage points (p.p.) between the time series in the model and the data in our sample of countries.[29] The average absolute deviations for the shares of hours in agriculture, industry, and services are 2 p.p., 6 p.p., and 7 p.p., and 4 p.p. for relative aggregate productivity. We conclude that the model captures the bulk of the labor reallocation and aggregate productivity experiences across countries.

To better understand our finding about aggregate productivity, recall that aggregate labor productivity is the sum of labor productivity in each sector weighted by the share of labor in that sector, i.e.,

$$\frac{Y}{L} = \sum_{i \in \{a,m,s\}} \frac{Y_i}{L_i} \frac{L_i}{L}.$$

As a result, the behavior of aggregate productivity arises from the behavior of sectoral

[28]While in most cases the model does well in reproducing the time series in the data, in some countries modifications to the simple model would be required in order to better account for the process of structural transformation and aggregate productivity growth – see Duarte and Restuccia (2007) for an application of wedges across sectors in Portugal. These richer environments, however, would require country-specific analysis. We instead maintain our simple model specification and leave these interesting country-specific experiences for future research.

[29]We measure the average absolute deviation in percentage points between the time series in the model and the data across countries as $\Upsilon = \frac{1}{JT_j} \sum_{j=1}^{J} \sum_{t=1}^{T_j} abs(x_{j,t}^d - x_{j,t}^m) \times 100$, where j is the country index and T_j is the sample size for country j.

labor productivity and the allocation of labor across sectors over time.[30] Since the model reproduces the salient features of labor reallocation across countries, aggregate productivity growth in the model is also broadly consistent with the cross-country data.

The model has implications for sectoral output in each country. Sectoral output is given by the product of labor productivity and labor hours. As a result, the growth rate of output in sector i is the sum of the growth rates of labor productivity A_i (which we take from the data) and the growth in labor hours L_i. The fact that the model reproduces well the cross-country patterns of the structural transformation implies that sectoral output growth is also well captured by the model.

The model also has implications for levels and changes over time in relative prices across countries. We first discuss the implications for changes in relative prices. Figure 9 plots the annualized percentage change in the prices of agriculture and services relative to manufacturing in the model and the data. The figure shows that the model captures the broad patterns of price changes in the data – since productivity growth tends to be faster in agriculture than in industry and in industry than in services in most countries, the tendency is for the relative price of agriculture to fall and the relative price of services to increase over time. We note that in the model, the only factors driving price changes over time are the growth in labor productivity across sectors. Of course, there are many other factors that can drive price changes over time so the model cannot capture all the changes.

Now we turn to the implications of the model regarding price-level differences across countries. Recall that the prices of agriculture and services relative to industry are given by the inverse of labor productivity $(A_m/A_a, A_m/A_s)$. The fact that the dispersion in productivity across rich and poor countries is large in agriculture and services relative to industry implies that the relative price of agriculture and services are higher in poor relative to rich countries. These implications may seem at first inconsistent with conventional wisdom about price differences across countries. We emphasize however that this conventional wisdom steams from observations about expenditure prices (often from PWT) instead of producer prices. For

[30]Note that in the above equation, sectoral labor productivity is measured at a common set of prices across countries.

instance, the conventional wisdom is that food is cheap in poor countries. This observation arises when the PPP-expenditure price of food is compared across countries using market exchange rates. But when the price of food is compared relative to other goods, food appears expensive in poor countries (see Summers and Heston (1991), page 338). Moreover, food expenditures include distribution and other charges and the distinction between producer and expenditure prices may differ systematically across countries.[31] In fact, producer-price data reveals an even more striking conclusion about the price of agriculture across countries: the evidence from FAO is that prices of agricultural goods are much higher in poor than in rich countries. This evidence is consistent with our findings that labor productivity in agriculture is lower in poor relative to rich countries.

Related is the conventional wisdom that the price of services is higher in rich relative to poor countries. This view steams again from observations about expenditure prices that may include a host of distortions that differ across countries (see Summers and Heston (1991) pages 338 and 339). While there is no systematic producer-price level data for services that can be compared with the price implications of the model, we focus instead on the indirect evidence from productivity measurements found in micro studies. Since the lower relative price of services in rich countries in the model steams from a higher relative productivity in services than in manufacturing compared to poor countries, we can use the available productivity measurements to indirectly assess the price implications of the model for services. The evidence suggests that labor productivity differences between rich and poor countries in services are larger than that of manufacturing industries as discussed by Baily and Solow (2001) from the McKinsey studies and other OECD studies discussed earlier. This evidence is consistent with our productivity findings and therefore with the price implications of the model. To summarize, while the lack of systematic price-level data prevents a definite conclusion about relative price differences across countries, the available evidence is consistent with the sectoral productivity findings and their price-level implications in the model.

[31] In the United States for instance, for every dollar expended on food, only 20 cents go to the farmer for the agricultural products.

4.3 Counterfactuals

We construct a series of counterfactuals aimed at assessing the quantitative importance of sectoral labor productivity on the process of structural transformation and aggregate productivity experiences across countries. We focus on two sets of counterfactuals. The first set is designed to illustrate the mechanics of positive sectoral productivity growth for labor reallocation and the contribution of productivity growth differences across sectors and countries for labor reallocation and aggregate productivity. The second set of counterfactuals focuses on explaining aggregate productivity growth experiences of catch-up, slowdown, stagnation, and decline by assessing the contribution of specific cross-country sectoral productivity patterns such as productivity catch-up in agriculture and industry and low productivity levels and the lack of catch-up in services.

4.3.1 The Mechanics of Sectoral Productivity Growth

We consider counterfactuals where in each case we set the growth rate of labor productivity in a sector to zero in all countries leaving the remaining growth rates as in the data. These counterfactuals illustrate the importance of productivity growth in each sector for labor reallocation and aggregate productivity. Summary statistics for these counterfactuals are reported in Table 2 and Figure 10. The statistics reported are the change between the last and first periods (in percentage points) in the time series of the share of hours in each sector and relative aggregate productivity. We start with the counterfactual for agriculture ($\gamma_a = 0$). No productivity growth in agriculture generates no labor reallocation away from agriculture: there is an average increase in the share of hours in agriculture of 2 percentage points (p.p.) in the counterfactual instead of a decrease of 26 p.p. in the model. As a result, much less labor is reallocated to services. This counterfactual has important negative implications for relative aggregate productivity for most countries regardless of their level of development: there is an average decline in relative aggregate productivity of 1 p.p. in the counterfactual instead of the 13 p.p. increase in the model. The effect of the counterfactual on labor reallocation implies that agriculture represents a larger share of labor than in the model. As a result, the negative impact of no growth in agriculture on aggregate productivity is magnified by the endogenous response of labor. Similarly, positive productivity growth in agriculture moves labor away from agriculture which dampens the positive impact of growth in this sector on aggregate productivity gains.

Next we turn to the counterfactual for industry ($\gamma_m = 0$). This counterfactual has no effect on the share of hours in agriculture (see equation 7). With no productivity growth in industry there is much less reallocation of labor away from industry into services compared to the model and thus industry represents a larger share of output in the counterfactual. As before, the negative impact of no growth in industry on aggregate productivity is magnified by the endogenous response of labor. The result is a process for relative aggregate productivity that is sharply diminished across countries: an average decline of 7 p.p. in the counterfactual instead of the catch-up of 13 p.p. in the model. An indeed the largest negative impact is on countries that observed the most catch-up in relative aggregate productivity in the model. Finally, no productivity growth in services ($\gamma_s = 0$) has a very small impact on labor reallocation across sectors.[32] Relative aggregate productivity declines by an average of 2 p.p. in this counterfactual. Note that the negative impact of this counterfactual on relative aggregate productivity is smaller than that of the case with no productivity growth in industry for all countries but three (Japan, Portugal, and Venezuela) even though services account for a larger share of hours than industry in most countries.

In the next counterfactual we assess the quantitative importance of differences in labor productivity growth across sectors and countries on aggregate productivity. We set labor productivity growth in each sector to the growth rate of aggregate labor productivity in the United States. The forth column in Figure 10 ($\gamma_i = \gamma^{\mathrm{US}}$) documents the results of this counterfactual for all countries in the sample. (See also Table 2.) The counterfactual has a substantial impact on the process of structural transformation. In particular, much less labor is reallocated away from agriculture and industry towards services. For instance, over the sample period the share of hours in agriculture fell on average 26 p.p. in the model and 17 p.p. in the counterfactual. In turn, the share of hours in services increased on

[32]This is due to two opposing effects of productivity growth in services on the labor allocation between industry and services which roughly cancel each other in the model. See Duarte and Restuccia (2007), page 42, for a detailed discussion of these effects.

average 36 p.p. in the model and 22 p.p. in the counterfactual. And indeed this different reallocation process together with the assumption about sectoral labor productivity growth explains a large portion of the experiences of catch-up and decline in aggregate productivity. For countries that catch-up in aggregate productivity to the United States in the model over the sample period, the average catch-up is 26 p.p. in the model and only 2 p.p. in the counterfactual. For countries that declined in relative aggregate productivity in the model over the sample period, the average decline is 11 p.p. in the model and only 2 p.p. in the counterfactual.[33]

We conclude from these counterfactuals that sectoral productivity growth generates substantial effects on labor reallocation which in turn are important in understanding aggregate productivity growth across countries.

4.3.2 Sectoral Productivity Patterns and Cross-Country Experiences

We now turn to the second set of counterfactuals where we assess the role of specific labor productivity patterns across sectors in explaining cross-country episodes of catch-up, slowdown, stagnation, and decline in relative aggregate productivity. As we documented in Figure 6, there has been a substantial catch-up in labor productivity in agriculture and industry across countries. To assess the importance of this sectoral catch-up for aggregate productivity we compute a set of counterfactuals were in each case we set the growth rate of labor productivity in a sector to the growth rate in that sector in the United States leaving the other sectors' growth rates as in the data ($\gamma_i = \gamma_i^{\mathrm{US}}$ for each $i \in \{a, m, s\}$). For completeness we also compute a counterfactual were all sectoral growth rates are set to the ones in the United States ($\gamma_i = \gamma_i^{\mathrm{US}}\ \forall i$). Table 3 summarizes the results for these counterfactuals. While there has been substantial catch-up of labor productivity in agriculture during the sample period (from an average relative productivity of 48 percent in the first period to 71

[33]Notice that this counterfactual does not eliminate all aggregate productivity growth differences across countries even though productivity growth rates are identical across sectors and countries and labor reallocation is much diminished as a result. For instance, in the counterfactual, relative aggregate productivity in Finland increases by 8 p.p. over the sample period and it decreases by 6 p.p. in Mexico. These movements in relative aggregate productivity in the counterfactual stem solely from labor reallocation across sectors (due to positive productivity growth) that have different labor productivity levels.

percent in the last period of the sample), this factor contributes little, about 10 percent, to catch-up in aggregate productivity across countries (1.3 p.p. of 12.8 p.p. in the model). The substantial catch-up in agricultural productivity produces a reallocation of labor away from this sector which dampens its positive effect on aggregate productivity growth.

Substantial has also been the catch-up in industry productivity. Unlike agriculture, this catch-up has a significant impact on relative aggregate productivity. Given that most countries have observed higher growth rates of labor productivity in industry than the United States, labor reallocation away from industry and toward services is diminished in the counterfactual for industry. On average, the share of hours in industry decreases 6.5 p.p. in the counterfactual compared to a decrease of 10.3 p.p. in the model. Figure 11 summarizes our findings for the effect of this counterfactual on relative aggregate productivity by reporting the difference in relative aggregate productivity between the last and the first period in the time series for each country. Industry productivity growth is important for countries that catch-up in aggregate productivity to the United States since these countries are substantially below the 45-degree line. In fact, we draw in this figure a dash-dotted line indicating half the gains in aggregate productivity in the counterfactual relative to the model. Many countries are in this category and some countries substantially below it such as Australia, Sweden, and the United Kingdom. For all countries, the average change in relative aggregate productivity is only 6 p.p. in the counterfactual instead of 12.8 p.p. in the model.[34] We conclude from this counterfactual that productivity catch-up in industry explains about 50 percent (6.8 p.p. of 12.8 in the model) of the relative aggregate productivity gains observed during the sample period.

Recall that, in contrast to agriculture and industry, there has been no substantial catch-up in services across countries and, as reported in Figure 6, there has been a decline in relative productivity in services for the richer countries. As a result, even though services represent an increasing share of output in the economy, we do not expect services to contribute much to catch-up in the model. This is confirmed in the third counterfactual as productivity catch-up

[34]Note that among countries that decline in relative productivity the effect of industry growth is not systematic and the gaps are not as large.

in services contributes about 15 percent of the catch-up in relative aggregate productivity (2.4 p.p. of 12.8 p.p. in the model). We note however that for countries that decline in relative aggregate productivity, lower growth in services than in the United States contributes substantially to this decline (-6.8 p.p. of -10.5 p.p. in the model, see Table 3). Among the developed economies – which feature a large share of hours in services – only Canada, New Zealand, and Sweden had lower productivity growth rates in services than the United States. In the model, Canada and New Zealand decline in relative aggregate productivity by 9 and 8 p.p. over the sample period, while Sweden observed a substantial catch-up in relative aggregate productivity but stagnated at around 82 percent during the mid-1970s. In the counterfactual, relative aggregate productivity increases by 3 p.p. in Canada, remains constant for New Zealand, and increases by 9 p.p. from the stagnated level in Sweden. Low productivity growth in services is essential for understanding these growth experiences of stagnation and decline among rich economies.

Recall also from Figure 6 that the level of relative productivity in services is lower than that of industry and that most countries failed to catch-up in services to the relative level of industry. For instance, the average relative productivity in services increased from 46 percent in the first period to 49 percent in the last period in the sample, whereas the average relative productivity in industry increased from 51 percent to 75 percent. In the last period of the sample, all countries except Austria, France, Denmark, the United Kingdom, and New Zealand feature lower relative productivity in services than in industry. Moreover, in many instances the differences in productivity between services and industry are substantial: around 40 percent lower in services in Spain, Finland, and Norway, around 60 percent lower in Portugal, and around 80 percent lower in Korea and Ireland. These features imply that the service sector represents an increasing drag on aggregate productivity as resources are reallocated to this sector in the process of structural transformation. To illustrate the role of low productivity in services and the lack of catch-up in accounting for the growth experiences of slowdown, stagnation, and decline, we compute a counterfactual where we let productivity growth in services be such that in the last period in the sample relative productivity in services is the same as relative productivity in industry in each country. While the impact of these different productivity growth rates in services on labor reallocation is somewhat limited, the impact on growth experiences across countries is quite striking: for countries that catch-up to the United States during the sample period, the average catch-up increases by almost 80 percent to 46 p.p. while for countries that decline there is instead a catch-up of 1.6 p.p. during the sample period (see Table 3). More importantly, these summary statistics hide the impact of productivity in services in explaining experiences of slowdown, stagnation, and decline observed in the time series. For this reason, Figure 12 plots the time path of relative aggregate productivity for all country experiences of slowdown, stagnation, and decline in relative aggregate productivity. The solid lines represent the model and the dash-dotted lines represent the counterfactual. This figure clearly indicates the extent to which low productivity in services and the lack of catch-up accounts for all these poor growth experiences.

To summarize, while productivity convergence in industry (and agriculture) are essential in the first stages of the process of structural transformation, the poor relative performance in services has determined a slowdown, stagnation, and decline in aggregate productivity. In fact, in the last period of the sample, almost all countries observe a lower relative labor productivity in services than in aggregate (see Figure 13). Since growth rate differences across countries in the service sector tend to be small and services represent a large and increasing share of hours in most countries, this suggests an increasing role of services in determining cross-country aggregate productivity outcomes.

4.4 Discussion

Our analysis of the structural transformation and aggregate productivity growth relies on a collection of closed economies. It is of interest to discuss the limitations and implications of this assumption for the results. Openness and trade can have two main effects in an economy. First, competition from trade can affect domestic productivity. Second, for a small open economy prices of traded goods reflect world-market conditions and not domestic productivity.

Regarding the effect of trade on productivity, we argue that the closed-economy assumption is not as restrictive for our analysis as it may first appear. To see this point, notice that the effect of openness on labor allocations and aggregate productivity is already embedded in the measures of labor productivity growth by sector which the analysis takes as given. For instance, we found that the growth rate of labor productivity in manufacturing for Korea was almost 3 times that of the United States. It is likely that openness to trade during this period can help explain this fact. Moreover, openness would imply that productivity differences across countries of those goods that are most tradable would tend to be small relative to the differences of those goods that are less traded. The productivity implications of the model are consistent with this broad prediction since differences in manufacturing productivity are smaller than the productivity differences in services. It is an interesting question for future research to assess the importance of trade for productivity convergence in manufacturing across countries and the lack of convergence in services which are mostly non-traded goods.

Regarding the effect of trade on relative prices, recall that the closed-economy assumption implies a one-to-one mapping from sectoral productivity growth to relative prices. An open-economy version of the model would tend to produce a weaker link between domestic productivity growth and relative prices. In fact, in a small-open economy relative prices are invariant to domestic productivity. As we discussed earlier, the relative price implications of the model are broadly consistent with the data which suggest that productivity growth is a substantial component of the movements in relative prices. To put it differently, we found a strong correlation between changes in relative prices and labor productivity growth across countries as documented in Figure 9. As a result, the labor allocations implied by the model are broadly consistent with the incentives that consumers face in these economies. We found that not all differences in relative prices are captured by the model. In particular, we found that the price of services relative to manufacturing increased faster in the model than in the data for many countries. This departure of the model from the data may arise not only from the closed-economy assumption, but also from other features of the data such as price distortions and barriers to labor reallocation across sectors. It is an interesting question why prices of tradable goods are not equalized across countries. The evidence suggests large departures from the law of one price. For instance, the price exercise from FAO on agricultural goods suggests large price differences across countries (see Prasada Rao (1993)) and the international macro literature documents large deviations in prices even for highly tradable goods.

Another potential avenue to assess the limitations of the closed-economy assumption of the model would be to compare the consumption and production implications relative to data. For instance, in the closed economy output and consumption shares are equal, but in the open economy they would differ. Unfortunately, this implication cannot be tested directly since consumption is measured as expenditures in final goods and any gap between production and consumption of goods may be due to processing, distribution and marketing services and other charges. But since for the more developed countries most of the trade occurs intra-industry – different cars or wines are shipped to and from countries – consumption and production shares of broad sectors would tend not to differ greatly in a country.

5 Conclusions

We documented the reallocation of labor over time between agriculture, industry, and services and the growth of sectoral labor productivity across countries. While countries are going through a common process of structural transformation, we found that there is substantial lag differences in this process. We also found that most countries tend to observe low productivity growth in services compared to agriculture or manufacturing even though there is a big variation in sectoral labor productivity growth across countries.

Using a model of the structural transformation that is calibrated to the growth experience of the United States, we showed that sectoral differences in labor productivity levels and growth explain the broad patterns of the process of structural transformation and aggregate productivity experiences across countries. We found that sectoral labor productivity differences across countries are large and systematic both at a point in time and over time. In particular, labor productivity differences between rich and poor countries are large in agriculture and services and smaller in manufacturing. Moreover, most countries have experienced substantial productivity catch-up in agriculture and industry but productivity in services has remained low relative to the United States. An implication of these findings is that, as countries move through the process of structural transformation, relative aggregate labor productivity can first increase (as labor moves from agriculture to industry) and later stagnate or decline (as labor moves from agriculture and industry to services). We find that sectoral productivity differences can account for the bulk of differences in the process of structural transformation and aggregate productivity experiences across countries.

This paper highlights the role of sectoral labor productivity differences for the structural transformation and aggregate productivity experiences across countries. We find that labor productivity catch-up in manufacturing explains about 50 percent of the gains in aggregate productivity across countries and that low labor productivity in services and the lack of catch-up explains all the experiences of slowdown, stagnation, and decline in relative aggregate productivity across countries. Thus, understanding the sources of cross-country differences in labor productivity levels and growth across sectors is crucial. In analyzing sectoral labor productivity levels and growth rates across countries, a number of interesting questions arise. What factors contribute to cross-country differences in labor productivity across sectors? Why were countries able to catch-up in manufacturing productivity but not in services? What are the barriers that prevent other developed economies to sustain growth rates of labor productivity in services as high as in the United States? How are trade openness and regulation related to these productivity differences across countries?

While there may not be a unifying explanation for all these observations, a recurrent theme in productivity studies at the sectoral level is that the threat or actual pressure of competition is crucial for productivity performance, see for instance Schmitz (2005) and Galdón-Sánchez and Schmitz (2002). Since services are less traded than manufacturing goods, there is a tendency for services to be less subject to competitive pressure and this may explain the larger productivity gaps in services relative to manufacturing across countries. Moreover, protected domestic industries may be the explanation to poor productivity performance in some countries. Since openness to trade would not generally have the desired competitive-pressure impact in services, other factors such as the regulatory environment may prove useful in explaining productivity differences across countries in this sector. Policies aimed at limiting regulations or government interventions that affect competition and productivity may explain productivity growth differences in services. For instance, it is often emphasized the role of land and size regulations affecting productivity in retail services, see for instance Baily and Solow (2001). As a first pass in providing some empirical support for this potential explanation to productivity differences across countries, we have correlated labor productivity differences in industry and services derived from our model to measures of trade openness and government regulation. We find that trade openness is strongly correlated to industry productivity but less so with services productivity, while measures of regulation (such as that from the World Bank's Doing Business) are strongly correlated with productivity in services. We leave a detailed investigation of these important issues for future research.

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A Data Sources and Definitions

We build a panel data set with annual observations for aggregate GDP per hour, and value added per hour and shares of hours for agriculture, industry, and services for 29 countries. The countries covered in our data set are, with sample period in parenthesis, Argentina (1950-2004), Australia (1964-2004), Austria (1960-2004), Belgium (1956-2004), Bolivia (1950-2002), Brazil (1950-2003), Canada (1956-2004), Chile (1951-2004), Colombia (1950-2003), Costa Rica (1950-2002), Denmark (1960-2004), Finland (1959-2004), France (1969-2003), Greece (1960-2004), Ireland (1958-2004), Italy (1956-2004), Japan (1960-2004), Korea (1972-2003), Mexico (1950-2004), Netherlands (1960-2004), New Zealand (1971-2004), Norway (1956-2004), Portugal (1956-2004), Spain (1960-2004), Sweden (1960-2004), Turkey (1960-2003), United Kingdom (1956-2004), United States (1956-2004), and Venezuela (1950-2004).

All series are trended using the Hodrick-Prescott filter with a smoothing parameter $\lambda = 100$ before any ratios are computed.

A.1 Aggregate Data

We obtain data on PPP-adjusted real GDP per capita in constant prices ($RGDPL$) and population (POP) from Penn World Tables version 6.2., see Heston, Summers, and Atten (2006); and we obtain data on employment (EMP) and annual hours actually worked per person employed ($HOURS$) from the Total Economy Database, see Conference Board and Groningen Growth and Development Center (2008a). With these data we construct annual time series of PPP-adjusted GDP per hour in constant prices for each country as $YLh = RGDPL \times POP/(EMP \times HOURS)$.

A.2 Sectoral Data

We obtain annual data on employment, hours worked, and constant domestic-price value added for agriculture, industry, and services for the countries listed above. The sectors are defined by the International Standard Industrial Classification, revision 3 (ISIC III) definitions, with agriculture corresponding to ISIC divisions 1-5 (agriculture, forestry, hunting, and fishing), industry to ISIC divisions 10-45 (mining, manufacturing, construction, electricity, water, and gas), and services to ISIC divisions 50-99 (wholesale and retail trade – including hotels and restaurants, transport, and government, financial, professional, and personal services such as education, health care, and real estate services).

A.2.1 Value Added by Sector

Value added by sector is obtained by combining data from the World Bank (2008), World Development Indicators online and historical data from the OECD National Accounts publications for the following countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Ireland, Italy, Japan, Korea, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Turkey, United Kingdom, and United States.

The data series from the World Bank's World Development Indicators are agriculture value added, industry value added, and services value added. All series are measured in constant local currency units, base year 2000 (with the exception of Turkey, 1987). These series are extended backwards using historical data from the OECD National Accounts publications, except for Korea. A combination of three OECD publications was used: National Accounts of OECD Countries (1950-1968), National Accounts of OECD Countries (1950-1961), and National Accounts of OECD Countries (1960-1977). The primary resource was the book covering the period from 1950 to 1968. We compute growth rates of the OECD data for corresponding variables for years prior to those available through the World Bank and apply them to the World Bank series.

Data on value added by sector for all Latin American countries in our data set (Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Mexico, and Venezuela) are obtained from the 10-Sector Database (see Conference Board and Groningen Growth and Development Center (2008b)). This database has data on value added in constant local prices for 10 sectors. These data are aggregated into value added in agriculture, industry, and services using the ISIC III definitions above.

A.2.2 Employment by Sector

The sectoral employment data is obtained from a variety of sources as well. We obtain data on civilian employment in each broad sector from OECD databases (Labor Force Statistics, Main Economic Indicators, and Annual National Accounts) for: Australia, Austria, Belgium, Canada, Finland, France, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Spain, Turkey, United Kingdom, and United States. Data for Portugal on sectoral employment is obtained from the Banco de Portugal (2006). The data is aggregated into the same three broad sectors. We extend this series forward to 2005 by using growth rates for each variable computed from EUKLEMS Database (2008). Data for Korea and all Latin American countries is obtained from the 10-Sector Database (see Conference Board and Groningen Growth and Development Center (2008b)). We aggregate this data into the three broad sectors using the ISIC III definitions above.

A.2.3 Hours Worked by Sector

We obtain data on hours of work per worker from the EUKLEMS Database (2008) for Australia, Austria, Belgium, Denmark, Finland, France, Ireland, Italy, Japan, the Netherlands, Portugal, Spain, Sweden, United Kingdom, and United States. This data cover the period 1970 to 2005. Data for Brazil, Canada, Chile, Colombia, Costa Rica, Greece, Mexico, Norway, New Zealand, and Turkey is obtained from International Labour Office (2008), Laborsta database. These series are much shorter; the time period covered varies by country but it starts after 1990 for all countries.

From these data, we compute the ratio of per-worker hours by sector relative to per-worker aggregate hours. In analyzing these ratios, we find that relative sectoral hours are remarkably stable over time for most countries and that these ratios are very close to one for many countries. Moreover, any deviations from one in relative hours across countries are not systematically related to the level of development. For each country, we use the average value of each of these ratios, denoted as h_i, $i = a, m, s$, to calculate shares of hours by sector and value added per hour by sector. Since the time series of sectoral hours are shorter than those of sectoral employment and value added, this simplification allows us to compute sectoral shares of total hours and value added per hour without shortening the time series. We do not have data on sectoral hours for Argentina, Bolivia, Korea, and Venezuela and we assume that $h_i = 1$ for these countries.

Total hours by sector are computed by multiplying employment with hours per worker in each sector. We construct value added per hour by dividing the series of value added with the corresponding series of total hours for each sector. Shares of hours by sector are simply the ratio of total hours by sector relative to total aggregate hours.

A.2.4 Prices by Sector

We compute implicity price deflators for each sector using data on sectoral value added at constant and current prices from the World Development Indicators. The price data is consistent with the sectoral definitions for labor productivity. It covers the period from 1971 to 2004.

Table 1: Parameter Values and U.S. Data Targets

Parameter	Value	Target
$A_{i,1956}$	1.0	Normalization
$\{A_{a,t}\}_{t=1957}^{2004}$	$\{\cdot\}$	Productivity growth in agriculture
$\{A_{m,t}\}_{t=1957}^{2004}$	$\{\cdot\}$	Productivity growth in industry
$\{A_{s,t}\}_{t=1957}^{2004}$	$\{\cdot\}$	Productivity growth in services
a	0.01	Long-run share of hours in agriculture
$\bar{a}$	0.11	Share of hours in agriculture 1956
$\bar{s}$	0.89	Share of hours in industry 1956
b	0.04	Share of hours in industry 1957-2004
ρ	-1.5	Aggregate productivity growth

Table 2: Sectoral Growth, Labor Reallocation, and Aggregate Productivity

	Change in Share of Hours			Change in Relative Aggregate Productivity
	Agriculture	Industry	Services	
All countries:				
Model	-25.5	-10.3	38.8	12.8
Counterfactual:				
(1) $\gamma_a = 0$	2.1	-13.7	11.6	-0.5
(2) $\gamma_m = 0$	-25.5	7.3	18.2	-7.0
(3) $\gamma_s = 0$	-25.2	-11.8	36.9	-2.2
(4) $\gamma_i = \gamma^{\text{US}}$	-16.8	-4.7	21.5	0.4
Catch-up countries:				
Model	-24.3	-13.5	37.8	25.8
Counterfactual:				
(1) $\gamma_a = 0$	4.9	-17.3	12.4	7.9
(2) $\gamma_m = 0$	-24.3	9.5	14.8	-1.5
(3) $\gamma_s = 0$	-23.8	-15.6	39.4	4.0
(4) $\gamma_i = \gamma^{\text{US}}$	-13.3	-4.5	17.8	1.6
Decline countries:				
Model	-27.6	-4.5	32.1	-10.5
Counterfactual:				
(1) $\gamma_a = 0$	-2.9	-7.2	10.1	-15.7
(2) $\gamma_m = 0$	-27.6	3.3	24.3	-16.8
(3) $\gamma_s = 0$	-27.6	-4.9	32.5	-13.3
(4) $\gamma_i = \gamma^{\text{US}}$	-23.2	-5.1	28.2	-1.9

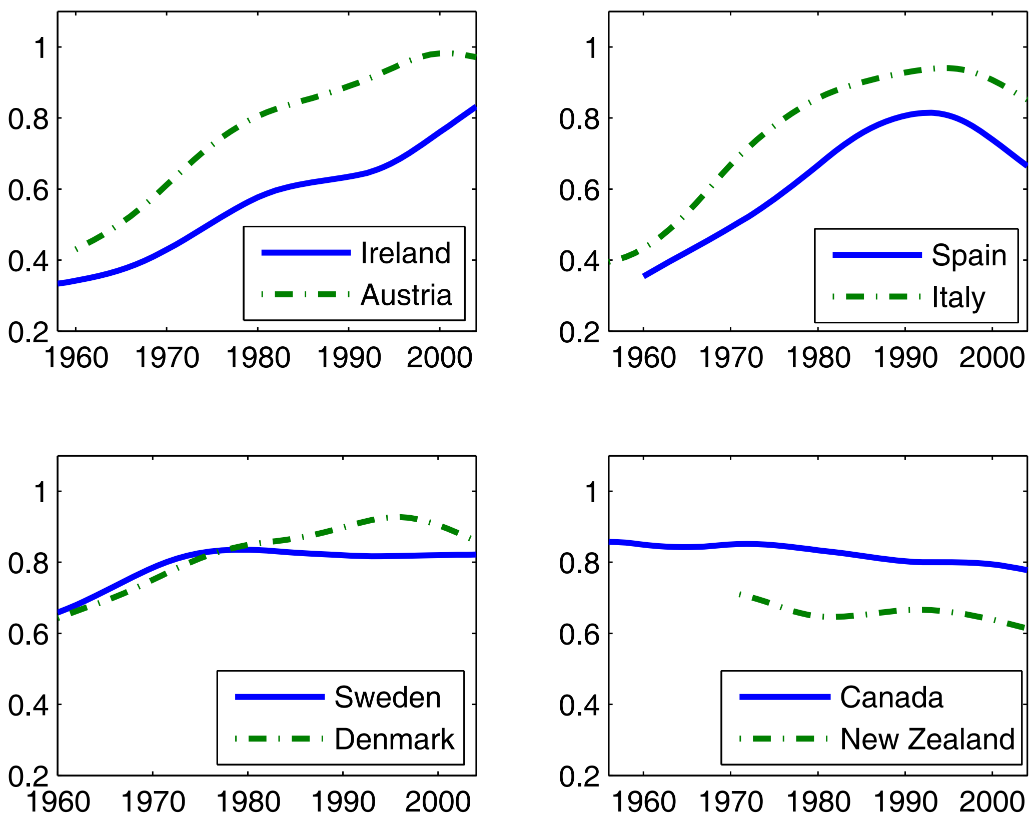
The table reports the average change between the last and first period in the time series (in percentage points) of each variable for the model and the counterfactuals. Counterfactuals (1) to (3) assume zero growth in labor productivity in a sector leaving the other sectoral growth rates as in the data. Counterfactual (4) assumes labor productivity growth in each sector equal to the aggregate productivity growth in the United States.

Table 3: Change in Relative Aggregate Productivity

	All countries	Catch-up countries	Decline countries
Model	12.8	25.8	-10.5
Counterfactual:			
(1) $\gamma_i = \gamma_i^{\mathrm{US}}$			
(1a) Agriculture	11.5	23.2	-9.4
(1b) Industry	6.0	13.9	-8.4
(1c) Services	10.4	18.3	-3.7
(2) $\gamma_i = \gamma_i^{\mathrm{US}}\ \forall i$	3.9	5.8	0.5
(3) Catch-up in Services	30.7	46.9	1.6

The table reports the average change between the last and first period in the time series (in percentage points) of relative aggregate productivity for the model and the counterfactuals. Counterfactuals (1a) to (1c) set the growth rate in a sector to the rate in the United States in that sector. Counterfactual (2) sets the growth rate of all sectors to the sectoral growth rates in the United States. Counterfactual (3) sets the productivity growth in services such that in the last period in the sample relative productivity in services is the same as relative productivity in industry in each country.

Figure 1: Relative GDP per Hour – Some Countries



Note: GDP per hour in each country relative to that of the United States.

Figure 2: Shares of Hours – Some Countries

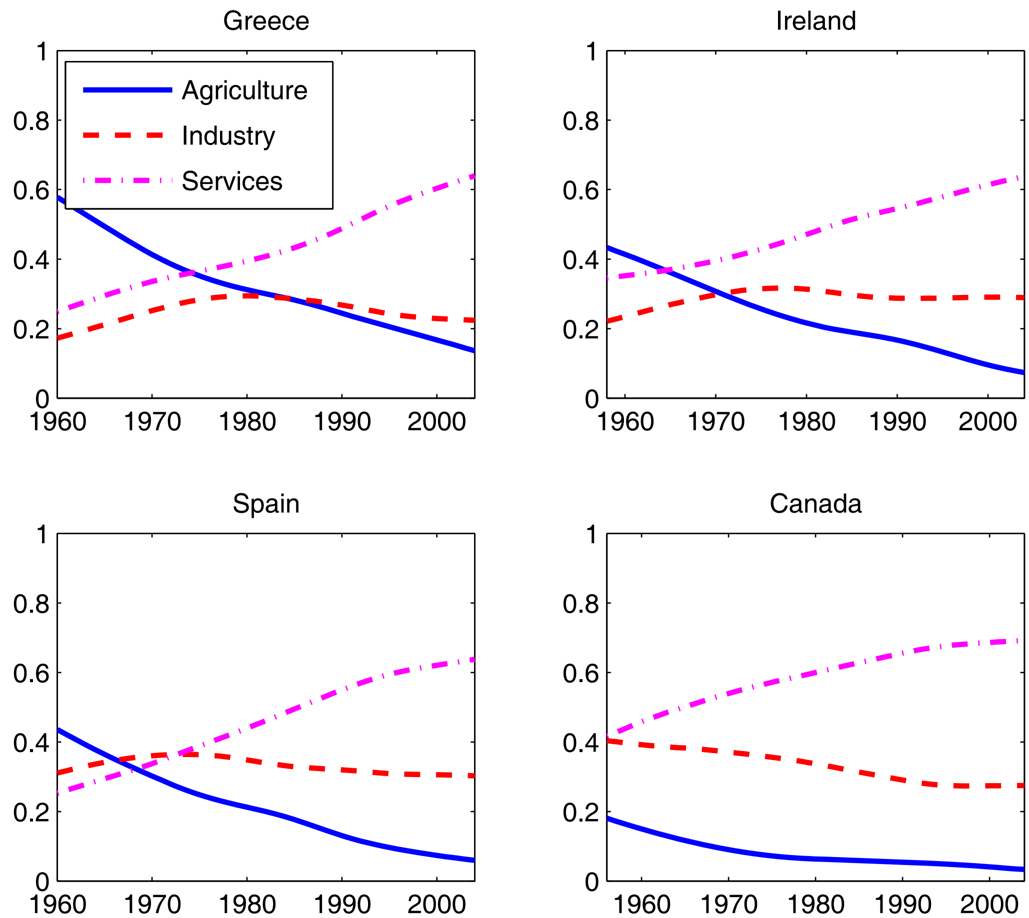
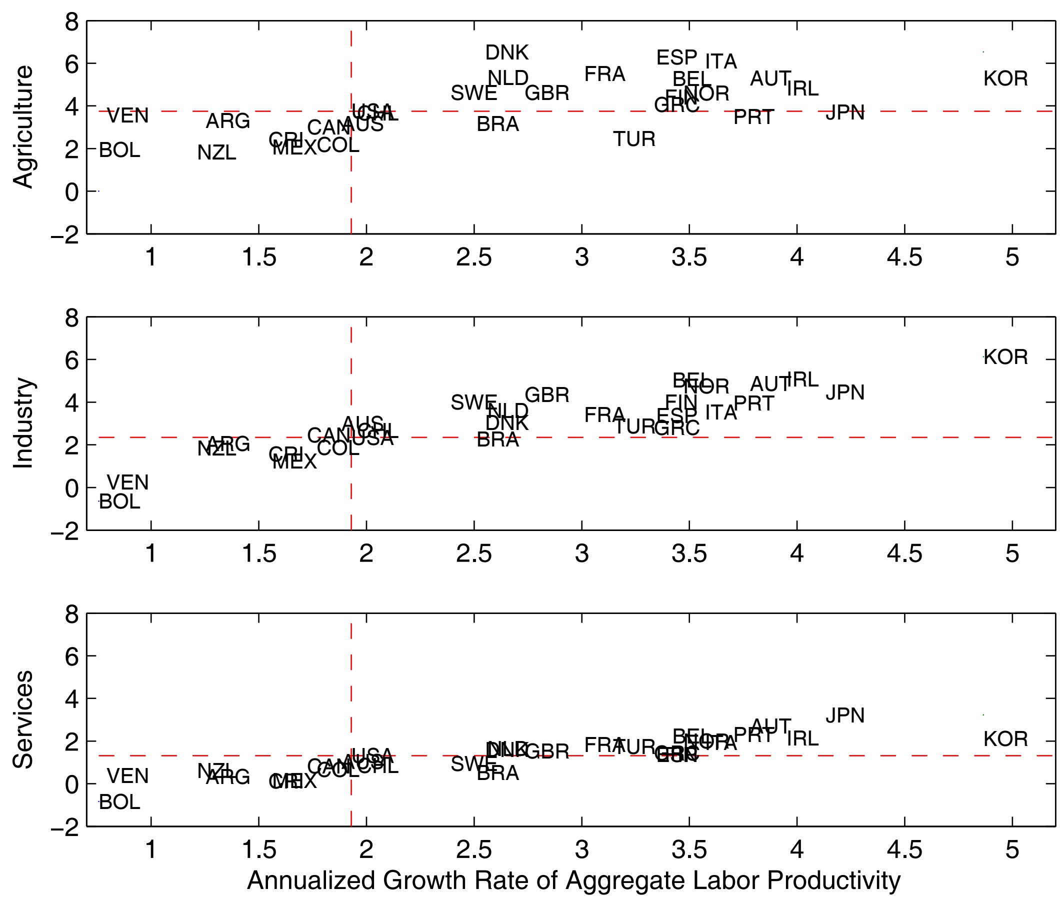


Figure 3: Sectoral Growth Rates of Labor Productivity (%)



Note: Aggregate labor productivity is GDP per hour while sectoral labor productivity is value added per hour in each sector. Annualized percentage growth rates during the sample period for each country. The horizontal lines indicate the sectoral growth rates observed in the United States and the vertical line indicates the aggregate growth rate of the United States.

Figure 4: Share of Hours by Sector - Model vs. U.S. Data

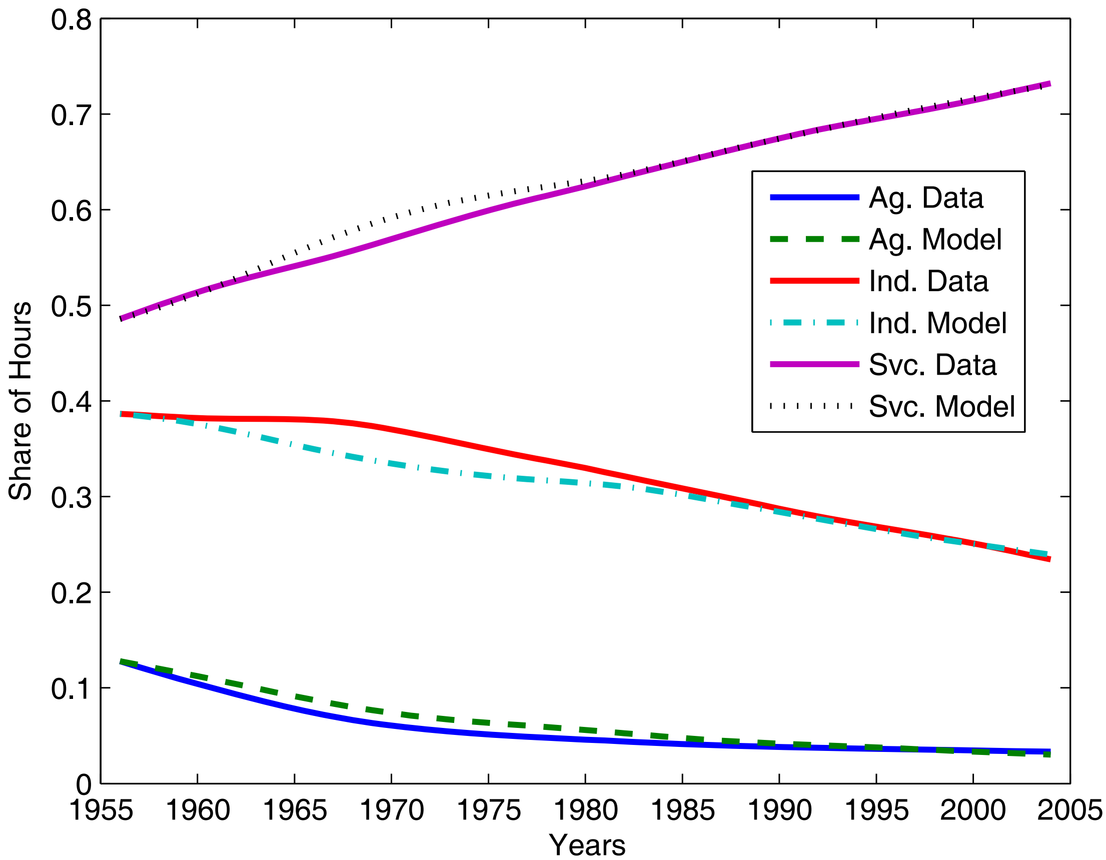
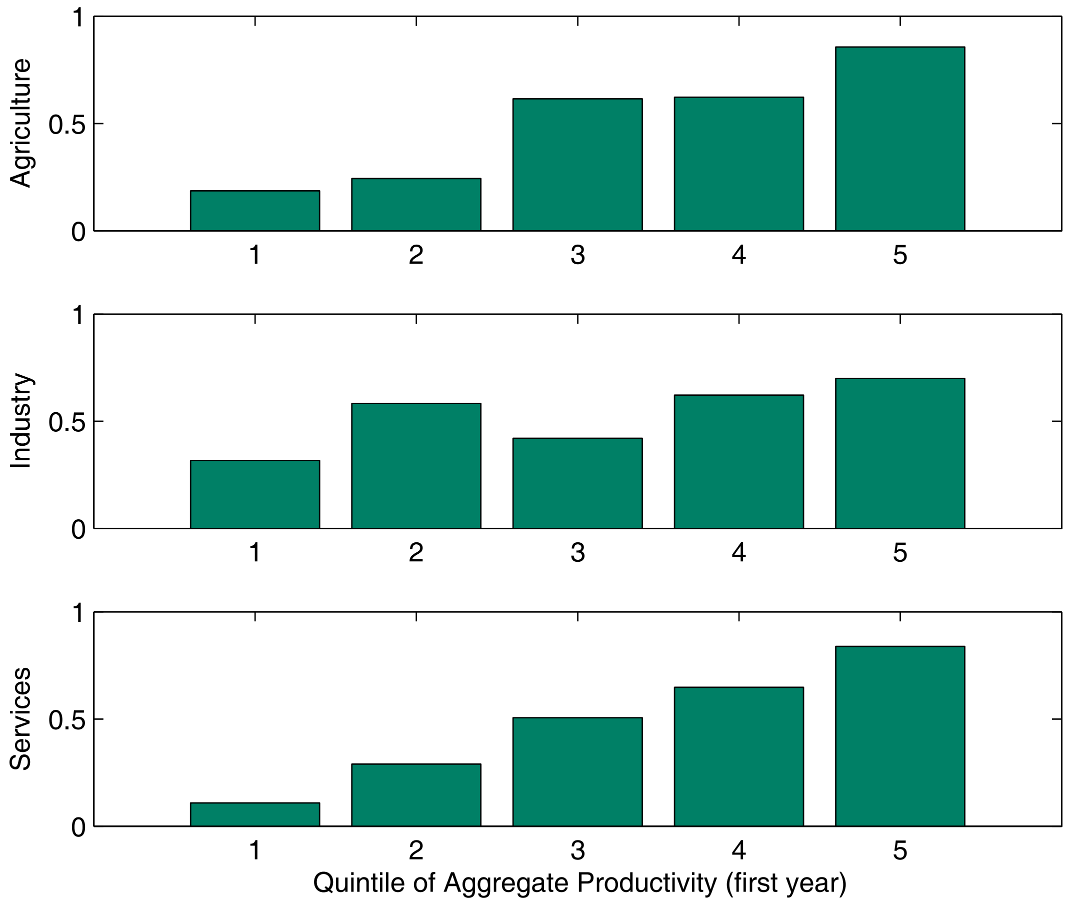
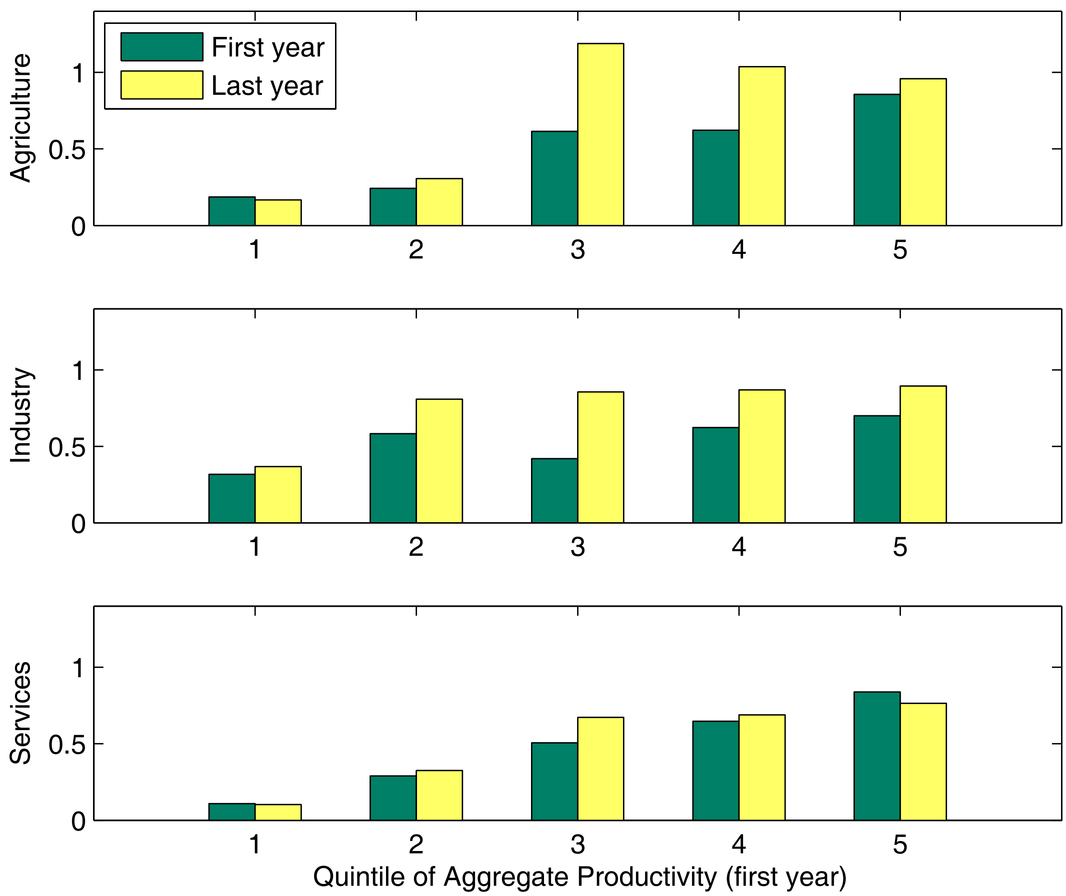


Figure 5: Relative Labor Productivity across Sectors - first year



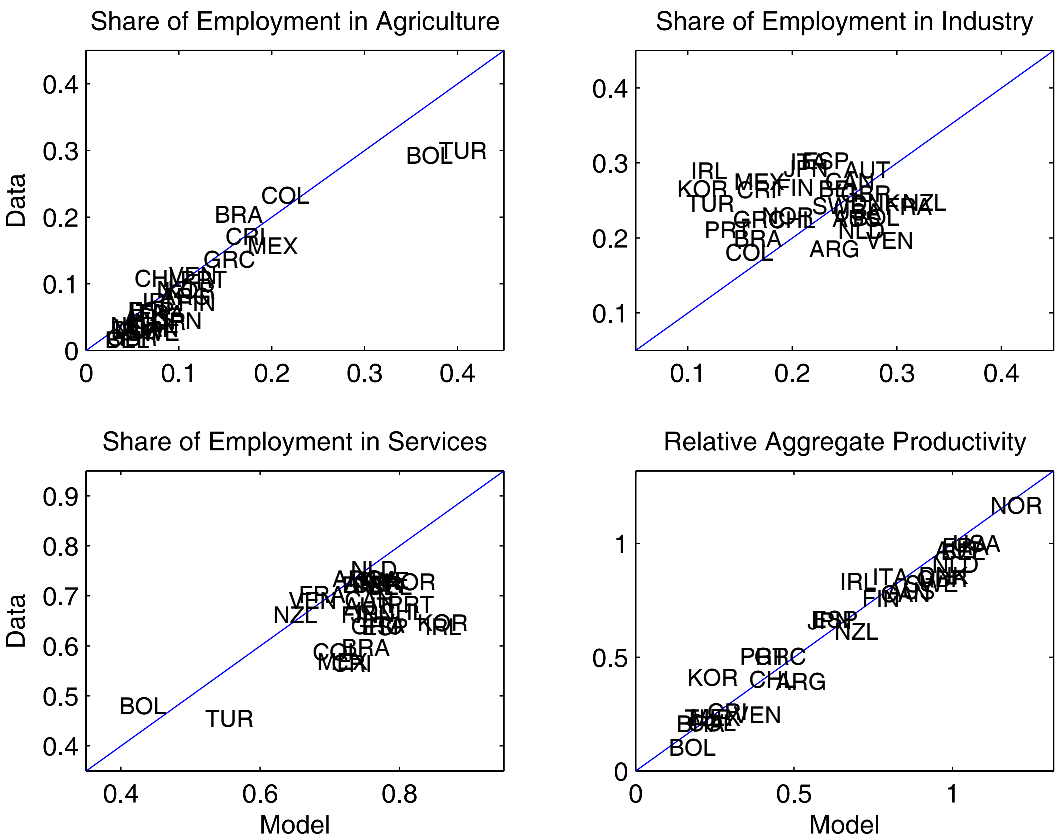
Note: Labor productivity relative to the level of the United States.

Figure 6: Relative Labor Productivity across Sectors - first and last years



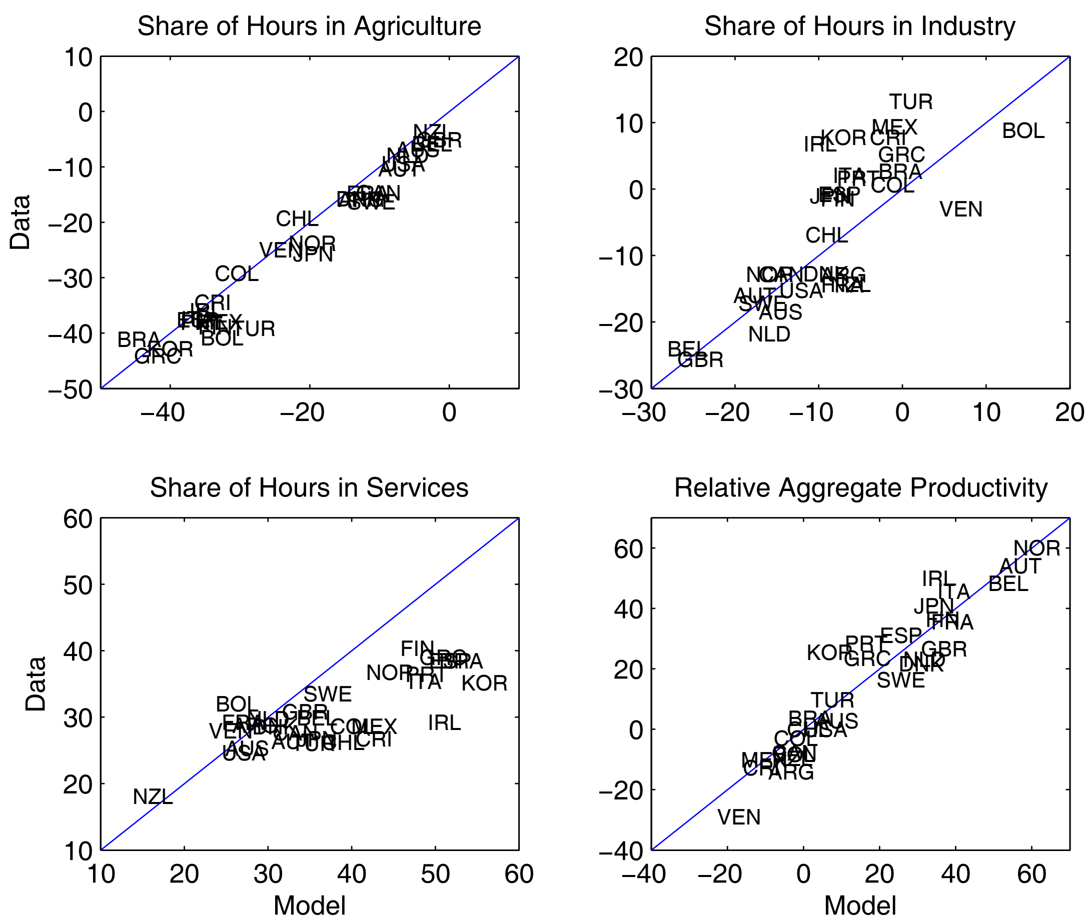
Note: Labor productivity relative to the level of the United States.

Figure 7: Model vs. Data Across Countries – Levels in the last year



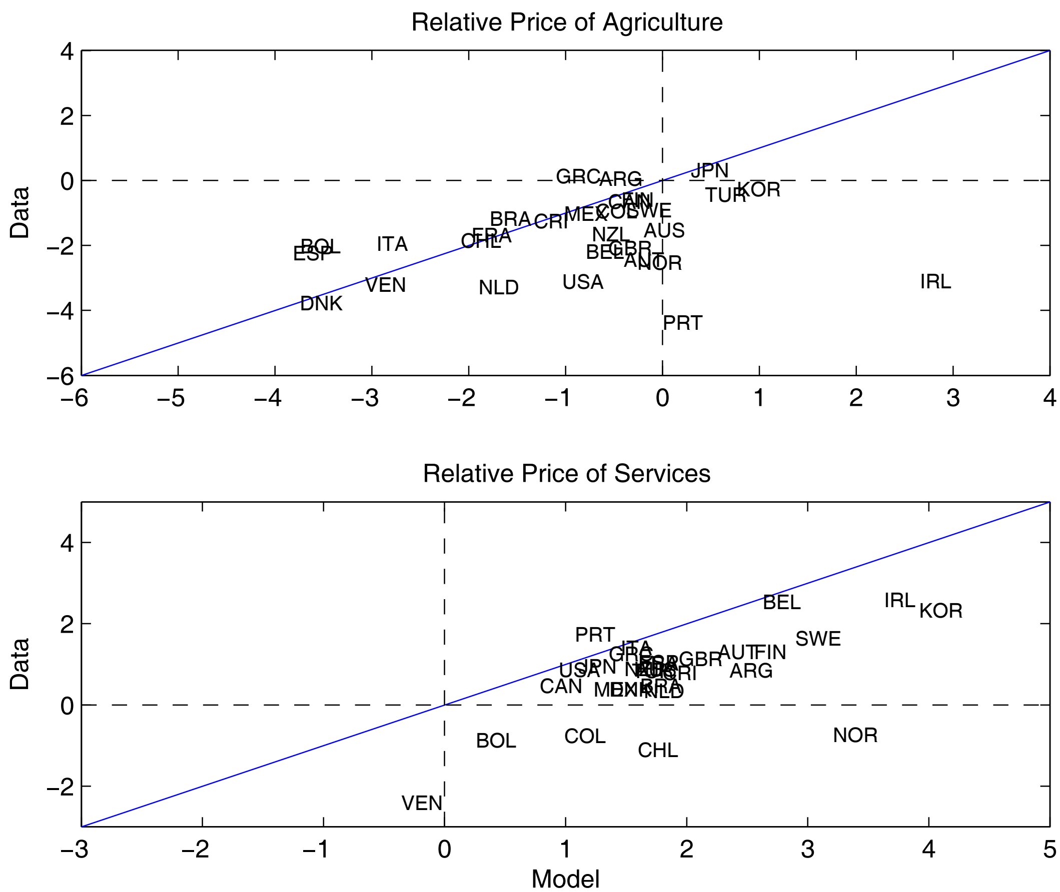
Note: Each plot reports the value for each variable in the last period for the model and the data.

Figure 8: Model vs. Data Across Countries – Changes



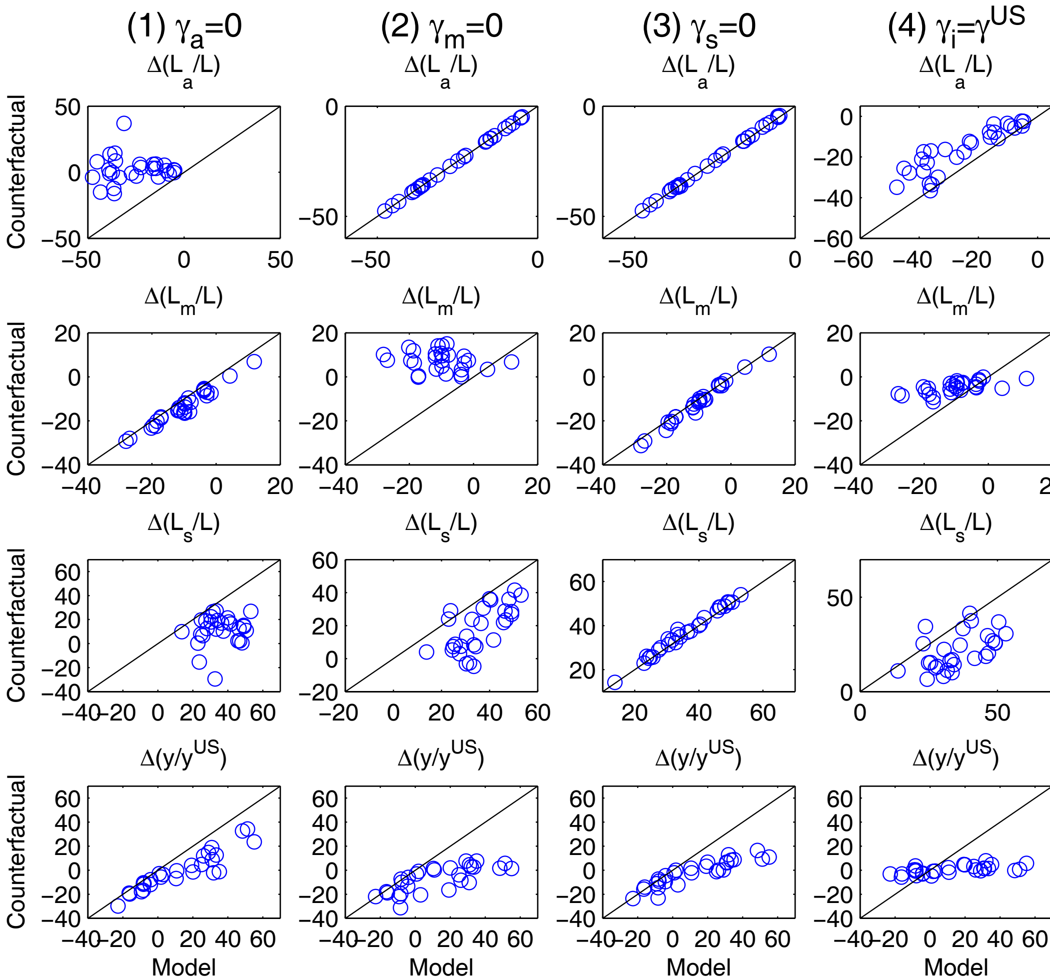
Note: Each plot reports the change between the last and first period (in percentage points) of each variable during the sample period in the data and in the model.

Figure 9: Changes in Relative Prices (%)



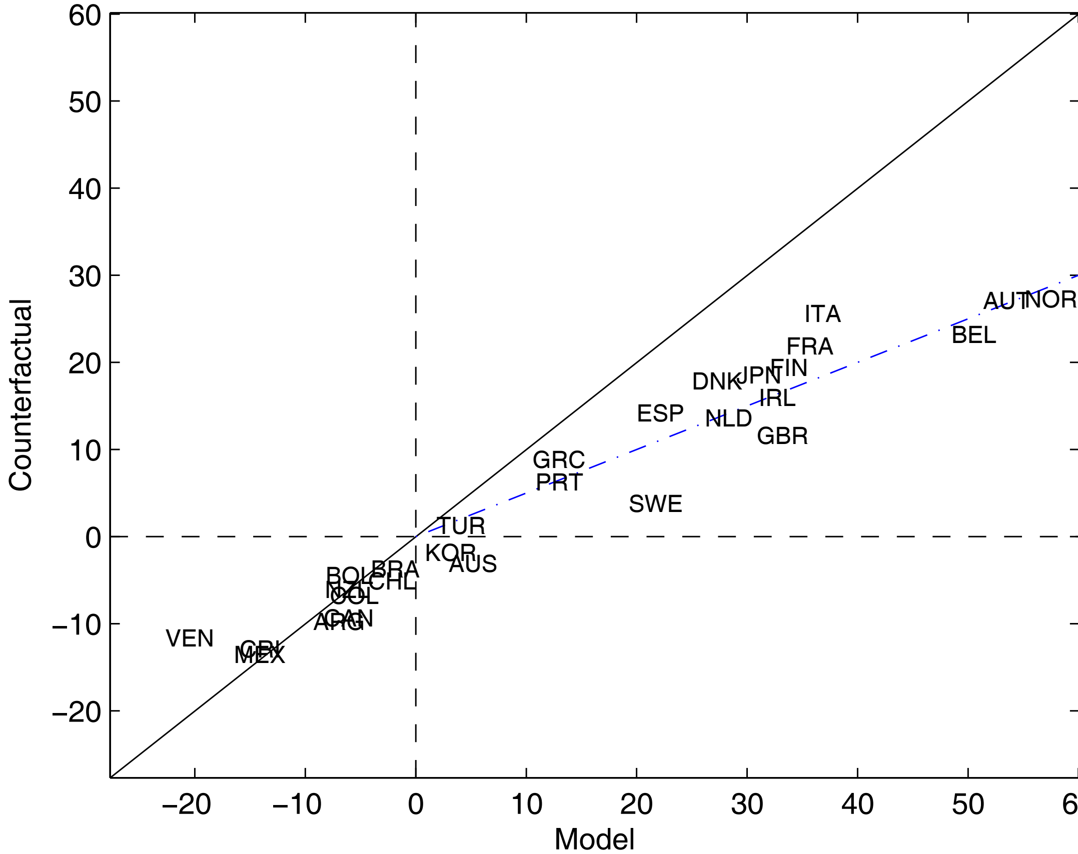
Note: Each figure reports the annualized percentage change of the variable in the time series in the data and in the model. Relative price of agriculture and services refer to the price of agriculture and services relative to industry. Data on relative prices cover the period 1971 to 2004.

Figure 10: The Mechanics of Sectoral Productivity Growth



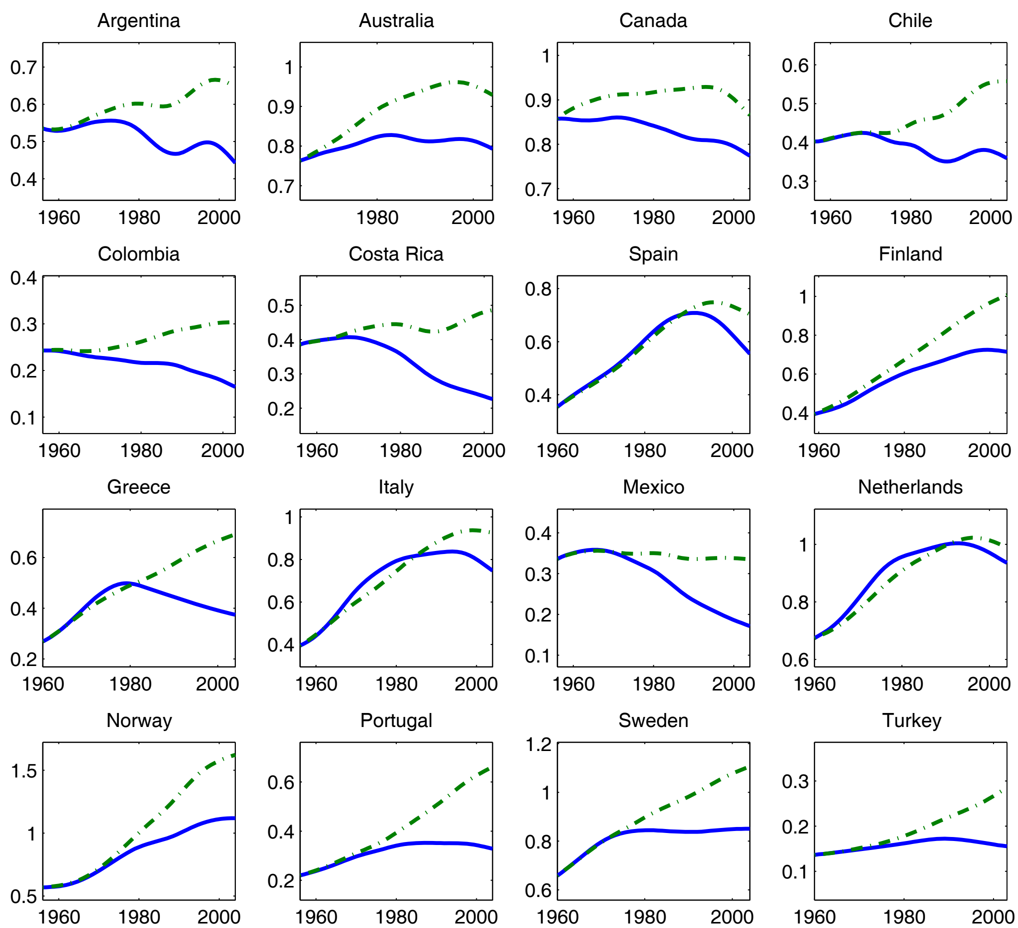
Note: Counterfactuals (1) to (3) set the growth rate of labor productivity in a sector to zero in all countries, leaving the other sectors as in the data for agriculture (first column), industry (second column), and services (third column). Counterfactual (4) sets labor productivity growth in each sector to aggregate productivity growth in the United States. Each panel plots the change between the last and the first period in the time series (in percentage points) of the share of hours in each sector and relative aggregate productivity in the model and in the counterfactual.

Figure 11: Change in Relative Aggregate Productivity – The Importance of Industry



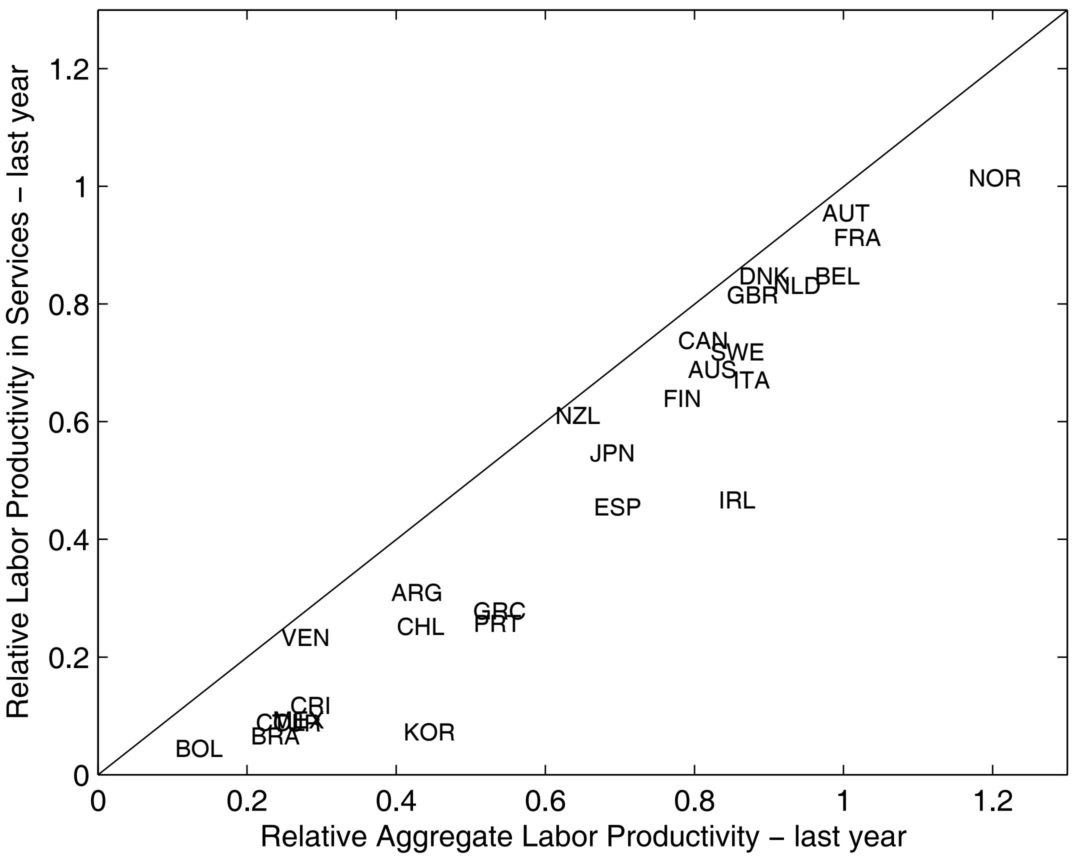
Note: This counterfactual sets the growth of labor productivity in industry in each country to the rate in the United States. The figure plots the difference between the last and first period (in percentage points) of relative aggregate productivity during the sample period in the model and in the counterfactual.

Figure 12: Relative Aggregate Productivity – The Importance of Services



Note: This counterfactual sets the productivity growth in services such that in the last period in the sample relative productivity in services is the same as relative productivity in industry in each country. Each panel plots aggregate labor productivity relative to that of the United States in the model and the counterfactual for each country which, during the sample period, experienced an episode of slowdown, stagnation, or decline. The solid line represents the model and the dash-dotted line the counterfactual.

Figure 13: Labor Productivity in Services across Countries – Last Period



Note: This figure plots relative labor productivity in services against relative aggregate productivity in the last period of the sample for all countries.