

Stages of Diversification and Industry Productivity Differences

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Abstract

Economies tend to diversify and then re-specialize as they develop. In an economy with many industries that experience different rates of productivity growth, these "stages of diversification" may obtain if initial conditions are skewed away from the industries that dominate economic structure in the long run as a matter of productivity-driven structural change. A calibrated multi-industry growth model with many countries replicates the main features of the "stages of diversification". We also present evidence that countries shift resources towards high-TFP growth manufacturing industries, and towards low-TFP growth sectors, consistent with the model.

Keywords: Stages of diversification, structural change, productivity differences, economic development.

JEL Codes: O11 O14 O33 O41.

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1 Introduction

Economic development is a joint process of economic growth and economic restructuring.¹ It is well known that economic development tends to involve a shift of resources away from agriculture and towards services.² In addition, Imbs and Wacziarg (2003, hereafter IW) show that there exist "stages of diversification": along the development path, countries appear to start out with employment concentrated in a few industries, diversifying until reaching a certain threshold in income per capita, beyond which they re-specialize. In other words, industrial specialization is U-shaped along the development path, a fact that is more general than the rise of services and the decline of agriculture.³ However, the literature has not developed an explicit theoretical account of these stages of diversification.

This paper shows that persistent productivity differences across industries can account for the observed patterns of economic restructuring along the development path. We study a multi-sector model economy that highlights TFP growth differences across sectors, and also across manufacturing industries. We show that the pattern of diversification followed by specialization can be accounted for simply by the dynamics of industry structure resulting from these differences, and we present empirical evidence that supports our theory.

Consider the following intuition. Suppose that markets are competitive, and that there are two goods that are substitutes in consumption. Then, persistent differences in TFP growth rates will lead to an increase in the GDP share of the industry with the most rapid productivity growth, as the good it produces will register a decline in its relative price. However, if the economy starts out being specialized in the *other* industry, then the economy will diversify until half of resources are devoted to each industry, after which it will appear to specialize again. The economy exhibits a "U" shaped pattern of specialization along the development path. Conversely, suppose the goods are complements. Then, persistent

¹The World Bank (2012) defines economic development as:

Qualitative change and restructuring in a country's economy in connection with technological and social progress. The main indicator of economic development is increasing GNP per capita (or GDP per capita), reflecting an increase in the economic productivity and average material wellbeing of a country's population. Economic development is closely linked with economic growth.

²See Gollin, Parente and Rogerson (2007), Restuccia, Yang and Zhu (2008) and Duarte and Restuccia (2010) for recent work documenting and analyzing the sources and consequences of these empirical regularities.

³IW document the "stages" across 9 broad sectors and also across 28 manufacturing industries.

differences in TFP growth rates lead to an increase in the GDP share of the industry with the *slowest* productivity growth, also generating a "U" shape if the economy starts out specialized in the other industry.⁴

We develop a multi-industry growth model in which productivity growth rates differ across industries, and calibrate initial productivity levels so as to reproduce the industry and sectorial composition of each of the 51 countries in the IW dataset in 1963. Then, we allow the structure of the model economies to evolve over time based on persistent productivity growth differences across industries. Along the development path, the labor shares of different industries evolve due to disparities between their TFP growth rates. Applying the same non-parametric method as IW to the model-generated series of industrial specialization, the calibrated model generates the U-shaped specialization pattern found in IW. Our results hold both within manufacturing and across broad sectors, and are robust to a number of variations in the calibration procedure. We conclude that differences in TFP growth across industries can indeed lead to the "stages of diversification," so that an important characteristic of the process of economic development is the reallocation of resources among industries with different rates of productivity growth.

Industry productivity growth rates are calibrated using US data. The use of common industry TFP growth rates across countries provides a clean experiment, as empirical country-specific rates could be influenced by industrial structure.⁵ At the same time, this assumption is consistent with the finding in Rodrik (2012) that there is unconditional convergence in labor productivity across countries among disaggregated manufacturing industries. We provide several robustness checks, using different productivity measures and allowing for productivity convergence dynamics, finding that the results are robust to variation in TFP growth rates across countries, as well as to different approaches to TFP measurement.

Critically, we provide evidence that, as they grow, countries *indeed systematically shift resources among industries with different TFP growth rates*, underlining the empirical relevance of the mechanisms in the paper for understanding the process of economic development. The literature suggests that goods are *substitutes* within manufacturing, whereas goods are *complements* across broad sectors: the model then predicts that resources shift

⁴Understanding the initial conditions themselves is beyond the scope of the paper. However, we do not impose that initial conditions are skewed one way or another: initial conditions are drawn from the data. We discuss initial conditions in Section 4.

⁵Industry size is viewed by some as a potential determinant of productivity-enhancing R&D and hence possibly of productivity growth – see the survey of Cohen (2011). We wish to isolate the impact of productivity growth on economic structure from any feedback that might occur.

towards *high-TFP growth industries* within manufacturing, whereas resources shift towards *low-TFP growth sectors* more broadly. This is exactly what we find in the data, providing strong corroborating evidence in support of the theory.

For most of the paper we focus on a simple model that delivers the main intuition and results. However, in the Appendix we develop a full general equilibrium version of the model. This version is close to the model of Ngai and Pissarides (2007, hereafter NP). NP show that persistent productivity differences across sectors can result in structural change, and study conditions under which this may occur along a balanced growth path. However, they focus on the behavior of agriculture and services, and do not study the "stages of diversification." We build on their work by performing a rigorous quantitative analysis of the implications of productivity-driven structural change for a large set of countries and industries. In addition, we find that the restrictions NP require for a balanced growth path with structural change do not appear to hold empirically – specifically, the elasticity of substitution across capital goods is not equal to one – so our general equilibrium analysis requires the computation of a multi-industry growth model in transition. This is something that to our knowledge has not been done before in an infinite-horizon multi-industry model with capital accumulation, and our methodology may be of independent interest.⁶

Duarte and Restuccia (2010) examine the impact of productivity differences across countries in agriculture and services on aggregate productivity. Our experiment is different: we assume that the rate of productivity growth in a given industry is constant across countries, and focus on accounting for economic structure. Our model is also much more disaggregated, allowing us to provide a more detailed picture of industrial structure along the development path at different levels of aggregation.⁷

The rest of the paper is organized as follows. Section 2 describes the link between industry productivity differences and industrial diversification in a simple framework, which captures the core intuition and delivers the key results. We develop the full general equilibrium version of the model in the Appendix so as to focus on the main results without having to bridge the technical gulf between the simple and full models for the benefit of the gen-

⁶Rogerson (2008), Duarte and Restuccia (2010) and others compute transition dynamics in growth models with many industries: however, their models do not have capital.

⁷Duarte and Restuccia (2010) also assume that preferences over the agricultural good are different above and below a subsistence threshold, in line with other papers that focus on agriculture such as Gollin, Parente and Rogerson (2007) and Restuccia, Yang and Zhu (2008). We abstract from such non-homotheticity of preferences to focus on the productivity mechanism: also, our industries and sectors are highly disaggregated, so that patterns of structural change among them are unlikely to depend on a subsistence requirement in one particular sector.

eral reader. Section 3 provides evidence supporting the predictions of the model regarding shifts in resources among industries and sectors with different TFP growth rates. Section 4 concludes with a discussion of possibilities for future work, including research into why less developed economies might have initial conditions that under-weigh high TFP growth industries.

2 Diversification and TFP Growth differences

We begin by describing the stylized facts of how industrial structure evolves along the development path, and by explaining how productivity differences across industries might account for these facts using a simple model. IW deliver results at the sector level, and also at the industry level within manufacturing.

2.1 Economic structure along the development path

IW use a nonparametric methodology to investigate the relationship between sectorial diversification and income. Manufacturing industry data are drawn from the INDSTAT3 database distributed by UNIDO, whereas sector-level data are provided by the ILO, and data on aggregate income per capita are from the Penn World Tables. The industry (or sector) share is defined as the share of manufacturing employment.

IW use the Gini coefficient of industry shares $GINI_{c,t}$ to measure the degree of industrial concentration in any country c at date t : the more equal the industry shares (i.e. the lower the Gini), the more diversified the economic structure.⁸ Then, they apply a procedure related to robust locally weighted scatterplot smoothing (lowess) to uncover the link between income per capita $GDP_{c,t}$ and specialization. Specifically, they regress the Gini coefficients of industrial specialization on income per capita with country fixed effects, using rolling income windows.

$$GINI_{c,t} = \hat{\alpha}_c(x) + \hat{\beta}(x) GDP_{c,t} + \varepsilon_{c,t}, \quad GDP_{c,t} \in [x - \Delta/2, x + \Delta/2]. \quad (1)$$

The income interval size Δ is fixed at \$5,000 (in 1985 dollars) and the midpoint x of the interval gradually moves away from the previous income range (the increment across regressions is \$25). Then, they plot the fitted Gini coefficients estimated at the midpoint of the

⁸Although IW focus on Gini coefficients, they use several other measures of specialization for robustness. We focus on Gini coefficients too, but results for other measures are available upon request.

income interval in each regression. They find a U-shaped relationship between Gini coefficients and income levels. Their U-shaped relationship is robust across sectors (ILO data) and within manufacturing (UNIDO data). Figure 1 reproduces their main results.

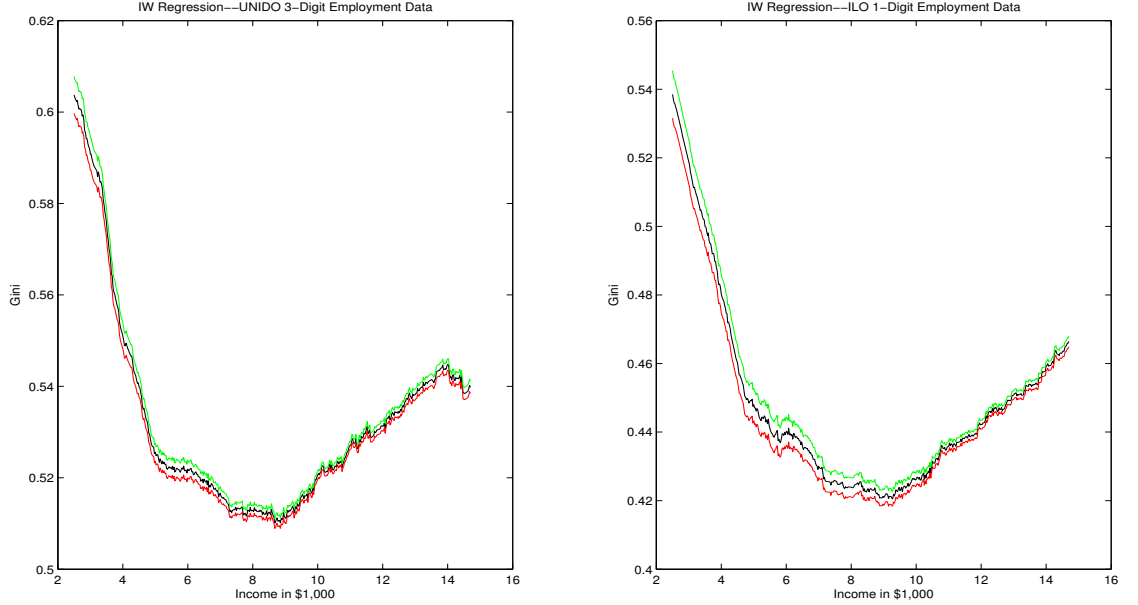


Figure 1. IW results. Each point in the Figure is the fitted value $\hat{\alpha}_c(x) + \hat{\beta}(x)x$ from equation (1), where x is GDP per capita. Confidence bands represent two standard errors of the coefficient $\hat{\beta}(x)$. The left panel is industry concentration within manufacturing estimated using INDSTAT3 data provided by UNIDO. The right panel is sectorial concentration across the entire economy estimated using ILO data. The middle line is the point estimate, whereas the other lines reflect the point estimate plus or minus the standard error of $\hat{\beta}(x)$, as in IW.

2.2 Productivity and economic structure

Suppose there are N competitive industries, with production functions of the form:

$$y_{it} = A_{it} K_{it}^{\alpha} n_{it}^{1-\alpha} \quad (2)$$

where productivity A_{it} grows according to $A_{it} = A_{i0} g_i^t$. The growth factor g_i may vary across industries, but capital shares α are assumed to be constant to highlight the productivity mechanism. Producers solve the problem

$$\max_{k_{it}, n_{it}} \{p_{it} y_{it} - w_t n_{it} - r_t K_{it}\} \quad (3)$$

where p_{it} is the price of good i , w_t is the wage and r_t is the rental rate of capital. The series for w_t and r_t are arbitrary.

Assume all these goods are consumed and that preferences display constant elasticity of substitution, so that⁹

$$u(\mathbf{y}_t) = \left[\sum_{i=1}^N \xi_i \times y_{i,t}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}, \quad \sum_{i=1}^N \xi_i = 1 \quad (4)$$

where ε is the elasticity of substitution among goods and $\mathbf{y}_t = \{y_{1t}, \dots, y_{Nt}\}$.

Let v_{it} be value added in industry i , so $v_{it} = p_{it}y_{it}$ where p_{it} is the price of good i . Then define the growth factor of value added G_{it} as:

$$G_{it} = v_{i,t+1}/v_{it}.$$

On the demand side, the consumer's first order conditions imply $\frac{p_{it}}{p_{jt}} = \left(\frac{y_{j,t}}{y_{i,t}} \right)^{\frac{1}{\varepsilon_s}} \frac{\xi_i}{\xi_j}$, so that

$$\frac{G_{it}}{G_{jt}} = \left[\frac{\frac{p_{i,t+1}}{p_{it}}}{\frac{p_{j,t+1}}{p_{jt}}} \right]^{1-\varepsilon}. \quad (5)$$

On the supply side, the optimal capital labor ratio is a constant across industries, so that $\frac{A_{it}}{A_{jt}} = \frac{p_{jt}}{p_{it}}$.¹⁰ Thus, in equilibrium (5) becomes:¹¹

$$\frac{G_{it}}{G_{jt}} = \left[\frac{g_i}{g_j} \right]^{\varepsilon-1}. \quad (6)$$

Let $s_{i,t}$ be the share of manufacturing value added (or employment) of industry i at date t . Given shares $s_{i,t}$ for one year t , we can compute shares for the next year $t+1$ by

⁹We abstract from intermediate goods because it would not significantly affect results. See the Technical Appendix for details. We also abstract from differences in α : Acemoglu and Guerrieri (2008) show that industry productivity differences continue to influence economic structure even when α may vary across industries, and furthermore evidence provided later in this paper suggests that differences in α cannot account for the "stages."

¹⁰To see this, the conditions can be written $p_{it}\alpha y_{it}/K_{it} = r_{it}$ and $p_{it}(1-\alpha)y_{it}/n_{it} = w_{it}$. Dividing one condition by the other we get that $\frac{1-\alpha}{\alpha} \left(\frac{K_{it}}{n_{it}} \right) = \frac{w_{it}}{r_{it}}$. Then, dividing any of these conditions for industry i by that for j yields the result.

¹¹Notice that, while we defined $G_{it} = v_{i,t+1}/v_{it}$, (6) would also hold if $G_{it} = n_{i,t+1}/n_{it}$. to see this, remember the household's first order conditions imply that $\frac{p_{it}}{p_{jt}} = \left(\frac{y_{j,t}}{y_{i,t}} \right)^{\frac{1}{\varepsilon_s}} \frac{\xi_{s,i}}{\xi_{s,j}}$. Plugging in the production functions and recalling that capital labor ratios are constant across industries yields $\frac{p_{it}}{p_{jt}} = \left(\frac{A_{jt}n_{jt}}{A_{it}n_{it}^{1-\alpha}} \right)^{\frac{1}{\varepsilon_s}} \frac{\xi_{s,i}}{\xi_{s,j}}$. Rearranging, we have that $\frac{n_{it}}{n_{jt}} = \frac{p_{it}y_{it}}{p_{jt}y_{jt}}$.

multiplying $s_{i,t}$ by $g_i^{\varepsilon-1}$, re-scaling so the shares add to one,¹² and repeating this procedure to get predicted shares for as many years as desired. Thus, given initial conditions, a value of ε , and productivity growth factors g_i , we can compute model-generated industry shares of manufacturing, and subject the resulting industry structure to the same nonparametric methodology as in IW to study whether productivity differences might be able to generate a U-shaped specialization pattern.

This might occur if "initial" industry composition is skewed towards low-tech industries. For example, suppose that $N = 2$ and that "specialization" is measured using the Gini coefficient. If s_{jt} is the share of industry j , then the Gini coefficient equals $0.5 - \min\{s_{1t}, 1 - s_{1t}\}$.¹³ Now suppose that $g_1 < g_2$. Then, if $\varepsilon > 1$, for a sufficiently low initial share of industry 1 the economy will start off specialized in industry 1 whereas in all periods thereafter the share of 2 will increase and that of 1 will decrease. Thus, the minimum of the two (s_{2t}) will rise until it reaches 0.5 and the Gini coefficient has dropped to 0. After this, the minimum of the two becomes s_{1t} and, as its share continues to decrease, the Gini coefficient rises again. Thus, for a time, specialization decreases, until s_{1t} drops below half – after which specialization will begin increasing again. Alternatively, if $\varepsilon < 1$, for sufficiently low initial productivity in 2 the economy will start off specialized in industry 2, whereas in all periods thereafter the share of 1 will increase, and the same dynamics obtain.

2.3 Calibration

We now examine whether the simple model presented above generates a U-shaped specialization pattern for the 28 manufacturing industries examined in IW. We use the initial industry shares in 1963 from the UNIDO employment data, and simulate a time series of future industry shares until 1992 using equation (6). We then include the same country-time pairs as IW, so that we have a model-generated unbalanced panel that is of the same dimensions as that in the IW database. We simulate industry shares for the 28 manufacturing industries in the ISIC revision 2 industry classification used by the UNIDO INDSTAT3 database, from 1964 until 1992 given the initial share in 1963 drawn from the UNIDO employment data. We use the value $\varepsilon = 3.75$, which is estimated in Ilyina and Samaniego (2012) by observing

¹²Given $s_{i,t}$, let $z_{i,t+1} = s_{i,t}g_i^{\varepsilon-1}$. Then $s_{i,t+1} = z_{i,t+1} / \sum_{j=1}^N z_{j,t+1}$.

¹³To see this, note that the Lorenz curve of industry composition when $N = 2$ is a line joining $(0, 0)$ to $(0.5, \min\{s_1, s_2\})$ and another line joining $(0.5, \min\{s_1, s_2\})$ to $(1, 1)$. The Gini coefficient is defined as the integral of the area above this line.

that equation (6) is equivalent to:

$$\log G_i = a + (\varepsilon - 1) \log g_i + \epsilon_i \quad (7)$$

where $a = \log G_j - \log g_j$ for some arbitrary industry j and ϵ_i is any unmodeled noise in the relationship. Thus, regressing value-added growth rates (or employment growth rates) on TFP growth rates yields a coefficient equal to $\varepsilon - 1$.¹⁴ Notice that by this estimate $\varepsilon > 1$, consistent with independent estimates from the literature on international trade.¹⁵

TFP growth data are computed using the NBER manufacturing productivity database. Note that the NBER industry classification is 4-digit SIC. We use Domar weights to convert NBER SIC industry TFP growth values into values for the ISIC revision 2 classification used by UNIDO. The value of g_i is the industry average over time.¹⁶

As a benchmark we assume that the values of g_i are constant across countries. The use of common TFP growth rates across countries provides the cleanest experiment, since it is only the initial conditions that vary across countries. For example, empirical country-specific TFP growth rates could be influenced by industrial structure: as discussed in the survey of Cohen (2011),¹⁷ industry size is viewed by some as a potential determinant of productivity-enhancing R&D and hence possibly of productivity growth. Later we will check the robustness of the results by using different TFP measures and allowing for convergence dynamics. We do not use country-specific measures of industry TFP growth because they do not exist for a wide sample of countries,¹⁸ and also because (as argued above) such measures may be endogenous to industrial structure.

GDP per-capita values are drawn directly from the data for each country-year combination. This can be thought of as having a country-specific TFP factor that affects all industries equally that is chosen to match GDP per person in each year – since it affects all industries equally, it does not impact economic structure. In the Appendix we develop and calibrate an explicit general equilibrium version of the model that also generates a series for real GDP.

¹⁴Ilyina and Samaniego (2012) estimate this coefficient using the industry TFP and value-added data reported in Jorgenson et al (2007).

¹⁵See the survey of Anderson and Van Wincoop (2004).

¹⁶See Table 6 in the Appendix for the values of g_i .

¹⁷At the same time it is worth noting that the evidence regarding this link is inconclusive, see Cohen (2011) and Ngai and Samaniego (2011).

¹⁸While in principle we could compute country-industry specific TFP growth rates using the country-specific UNIDO data, we found that in many cases the resulting rates were absurdly high or low. We interpret this as indicating that the investment data in those countries are likely subject to significant measurement error.

We also perform this exercise for the 9 sectors in the ILO data, which cover the entire private economy.¹⁹ This requires an independent calibration of the model. We take the manufacturing sector value of g_i to equal the average value derived from the NBER productivity database. Then, we calibrate g_i for the other sectors using their inverse price growth rates relative to manufacturing, using price data drawn from the US Bureau of Economic Analysis. We also require a different value of ε . We estimate that ε is not significantly different from zero, as in Herrendorf, Rogerson and Valentinyi (forthcoming), and set $\varepsilon = 0$ across broad sectors.²⁰

2.4 Results

We follow the IW methodology and regress Gini coefficients generated from our TFP growth simulation on income per capita. Our results display a similar U-shaped relation between sector concentration and income levels: see Figure 2. In addition, the turning point is roughly \$9,000, as found by IW, something that lends weight to the empirical relevance of the productivity mechanism.

¹⁹The 9 sectors are Agriculture, Hunting, Forestry and Fishing; Mining and Quarrying; Mining and Quarrying; Electricity, Gas and Water; Construction; Wholesale and Retail Trade and Restaurants and Hotels; Transport, Storage and Communication; Financing, Insurance, Real Estate and Business Services; and Community, Social and Personal Services. See Table 5 in the Appendix for the g_i values.

²⁰We estimated equation (7) using US time series from the ILO database, allowing for autocorrelated errors and obtained an estimate of $\varepsilon - 1 = -0.84$ with a standard error of 0.31. Thus, the estimate of ε is not significantly different from zero. We repeated this procedure pooling the data for all countries and using country fixed effects, obtaining an estimate of $\varepsilon - 1$ around -1.16 , with a standard error 0.19 such that once more ε is not significantly different from zero.

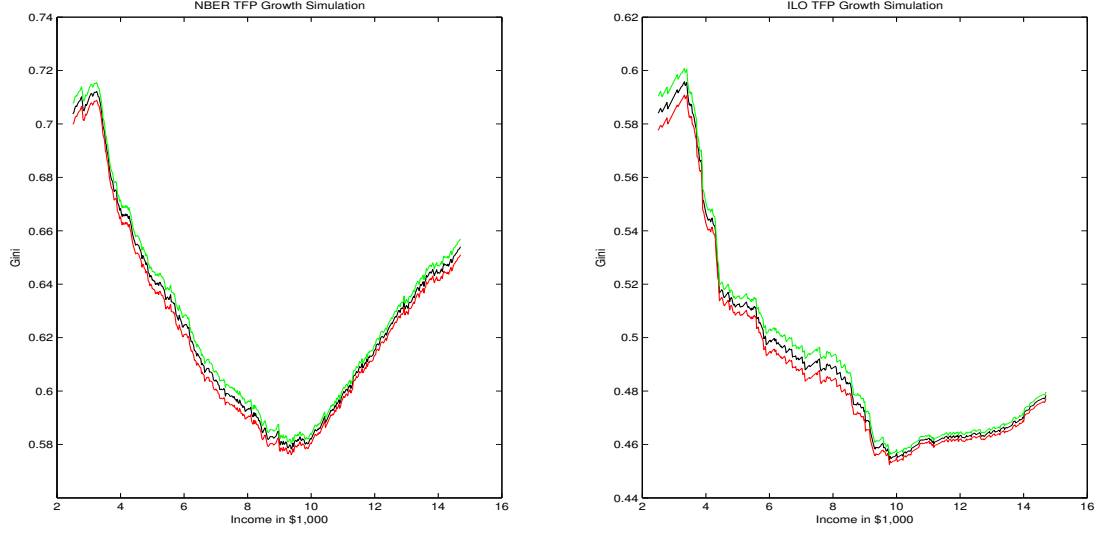


Figure 2. Industry structure along the development path in the simple model.

The left panel is the relationship between income and specialization within manufacturing. The right panel is the same relationship across broad sectors.

For robustness, we derive some alternative measures of TFP growth for manufacturing. Using the UNIDO dataset, we compute the TFP growth rates for the 28 UNIDO manufacturing industries in the United States using the following equation:

$$\ln(TFP_{it}) = \ln(Y_{it}) - (1 - \alpha) \ln(L_{it}) - \alpha \ln(K_{it}) \quad (8)$$

where Y_{it} is the production index, L_{it} is the total amount of labor and K_{it} is capital used in industry i at time t .

In addition, equation (5) suggests using inverse price growth rates to measure industry TFP growth. The price index is computed using value added divided by the production index from the UNIDO dataset.²¹ Both TFP and price growth rates are averages over the period 1963 – 1992 (see Table 6 in the Appendix). TFP growth rates computed this way are highly correlated with those derived from the NBER data, with a correlation coefficient of 0.6 (significant at the 5 percent level). The TFP growth and price growth series based on UNIDO data are highly negatively correlated with a coefficient of -0.9 (significant at the 5 percent level). All of this is encouraging as to the robustness of the productivity measures.

²¹Recall that value added $v_{it} = p_{it}y_{it}$. The assumption is that growth in the UNIDO industrial production index proxies for growth in y_{it} .

We simulate industry shares following equation (5) for UNIDO price growth and (6) for TFP growth and apply nonparametric methodology to model simulated Gini coefficients on income. Again, we obtain a U-shape in both cases, see Figure 3.

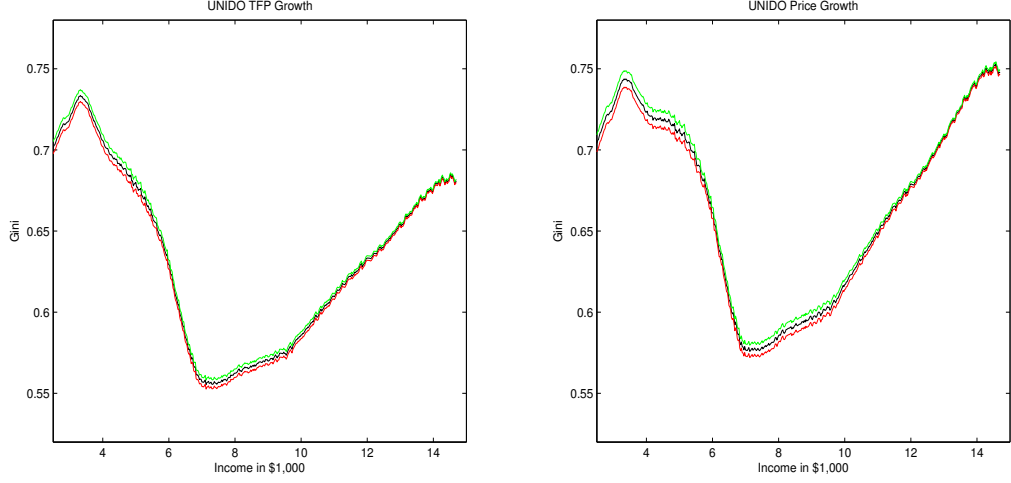


Figure 3. IW nonparametric regression using simulated industry concentration measures based on equation (6) using INDSTAT3 TFP growth rates, and based on equation (5) using INDSTAT3 price growth rates.

Finally, using the model itself, we can map between productivity growth rates and changes over time in employment shares by means of equation (6), setting the errors $\epsilon_t = 0$. We use this procedure to back out a measure of productivity growth we call g_i^{median} , which will be the median productivity growth factor implied by changes in employment patterns around the world (details below). We repeat the above experiments using g_i^{median} for all countries, again providing a clean experiment that abstracts from all country differences other than initial conditions.

All that is required to use (6) to back out productivity growth values from country employment data is knowing g_{jct} for some benchmark industry j in each country. We assume that in all countries and dates the productivity growth rate is the same in industry 342, Printing and Publishing. We choose this industry because in the NBER data $g_j \simeq 1$, for industry 342, i.e. there is essentially no total factor productivity growth in this industry. At the sector level, we assume that productivity growth is the same in all countries for Community, Social and Personal Services, which has the lowest g_i value among the sectors.

Having generated series for g_{ict} as described above, we compute g_{ic} , the average of the time series for each country and industry. The measure g_i^{median} is simply the median value

of g_{ic} for each i . Note that, since the country with the median value will vary by industry i , no country's employment patterns correspond to g_i^{median} , even though g_i^{median} is derived from the employment data.

First, it turns out that g_i^{median} is very highly correlated with the values of g_i calibrated using NBER data. Within manufacturing the correlation is 0.40 and across sectors it is 0.70, both significant at the five percent level. Second, Figure 4 displays the link between specialization and development using the basic model, using g_i^{median} as a measure of productivity growth. Again, the findings are robust.

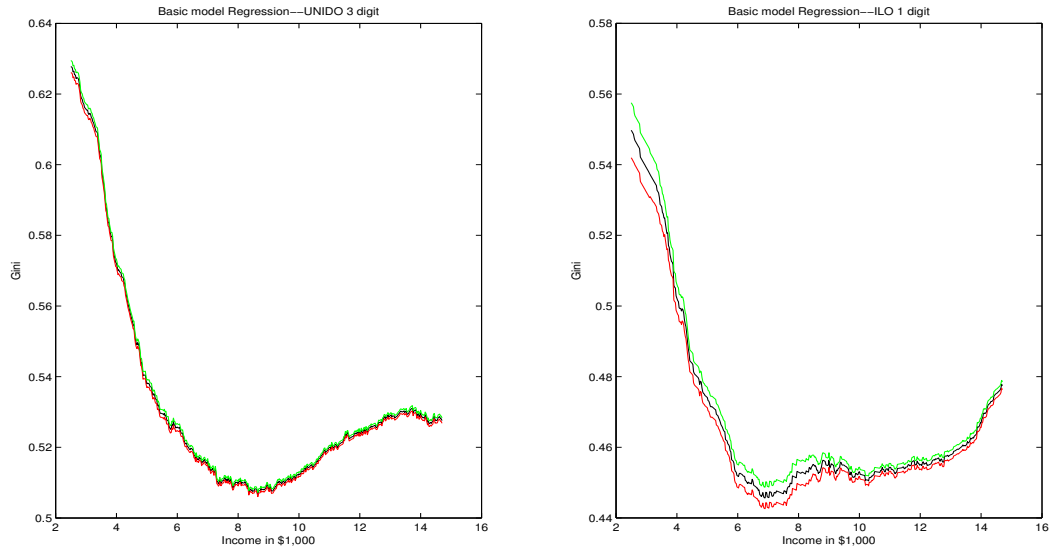


Figure 4 - Patterns of specialization in the basic model using g_i^{median} . This is the median TFP growth rate across countries measured using employment patterns as described in the text.

2.5 Country differences in Productivity Growth

The above exercise assumes that g_i is constant across countries. It is interesting to examine how sensitive the results are to this assumption. We draw on the finding of Rodrik (2012) that there is unconditional convergence in productivity levels across manufacturing industries. This would suggest that less developed economies have productivity values such that $g_{ict} \rightarrow g_i$ over time.²²

²²Unfortunately industry TFP data exist for only a small set of mostly developed countries. The finding of Rodrik (2012) relates to labor productivity: however it is hard to think of reasonable conditions under which labor productivity would converge while TFP does not. Note also that Rodrik (2012) tests for convergence in productivity *levels*, which is a stronger condition than convergence in growth rates.

Suppose that

$$g_{ict} = g_{ct} g_i f(x_{c,t})$$

where $x_{c,t} = Y_{c,t}/Y_{US,t}$, the relative GDP gap between country c and the United States, and g_{ct} is some country-specific productivity term. In the basic model, changes in the industry shares of manufacturing $G_{ict} = s_{i,c,t+1}/s_{ict}$ follow

$$\frac{G_{ict}}{G_{jct}} = \left(\frac{g_{ct} g_i f(x_{c,t})}{g_{ct} g_j f(x_{c,t})} \right)^{\varepsilon-1} = \left(\frac{g_i}{g_j} \right)^{\varepsilon-1}.$$

Thus the only way in which convergence could affect the results is if the convergence function f is different *across industries*. For example, suppose that

$$g_{ict} = g_{ct} g_i f_i(x_{c,t}) = g_{ct} g_i^{x_{c,t}^{\eta}}$$

If $\eta < 0$, poorer countries experience disproportionately rapid convergence in high- g_i industries, capturing the idea that in high- g_i industries there is greater room for catchup. If $\eta > 0$, then the reverse is the case – catchup is relatively slow in high- g_i industries, as in the model of Ilyina and Samaniego (2012) where barriers to technology transfer in less-developed economies (such as financing constraints) limit the R&D that would be necessary for them to catch up in high-tech industries.²³

To explore the impact of industry-specific convergence, we solve the manufacturing model with values $\eta \in \{-0.3, 0.3\}$. A value of -0.3 implies that the difference in $\log g_i$ between any two industries or sectors is doubled in a country with 10 percent of US GDP per head. A value of 0.3 implies that the difference in $\log g_i$ between any two industries or sectors is halved in a country with 10 percent of US GDP per head.²⁴

The results show that, although the exact shape of the curve is sensitive to the value of η , the U-shape in manufacturing is preserved, see Figure 5. The results with $\eta = 0.3$ are better in the sense that, when $\eta = 0.3$, the initial diversification stage is monotonic, whereas in the benchmark results the lowest income countries seemed to display a little specialization at first.²⁵ Thus, the results are robust to allowing for unconditional convergence

²³Note that in the calibrated model of Ilyina and Samaniego (2012) productivity growth in poor countries is relatively fast and convergence takes place: it is in a *relative* sense that catchup is slower in high- g_i industries.

²⁴To get a sense of how much productivity growth rates can vary around the world, Duarte and Restuccia (2010) find that labor productivity growth rates in agriculture is 1.4 percent higher than in manufacturing in the US, and that this gap varies across countries by between -0.8 percent and 3.5 percent. Thus a value of $\eta = 0.3$ is not unreasonable.

²⁵In the Technical Appendix we show that the same is the case with the UNIDO-based TFP measures and the UNIDO-based price measures.

in industry productivity growth rates – particularly if convergence is slower in high-TFP growth manufacturing industries, e.g. due to barriers to technology transfer.

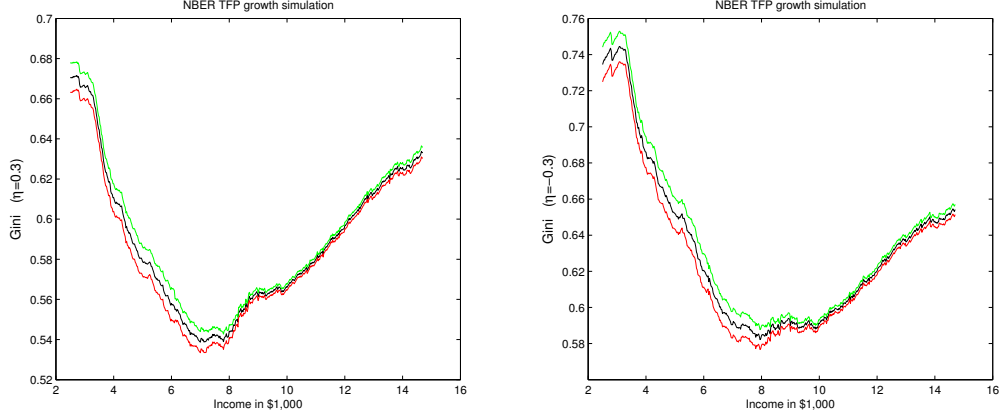


Figure 5 - Industry structure along the development path allowing for convergence in TFP growth rate across countries. Productivity growth g_{ict} equals $g_{ct}g_i^{x_{c,t}^\eta}$ where the output gap $x_{c,t}$ is defined as $Y_{c,t}/Y_{US,t}$.

2.6 General equilibrium

There are several reasons why it is interesting to extend the results to a general equilibrium version of the simple model. First, manufacturing can be separated into capital goods and non-capital goods, which serve different purposes and which may hence have different elasticities of substitution. Second, the share of capital goods within manufacturing will be determined by agents' investment behavior, whereas the share of non-capital goods will be determined by their consumption behavior. Third, capital also includes structures, built by the construction sector yet not part of manufacturing. Fourth, the basic model does not generate a series for income per capita: we simply took the data values as given. The general equilibrium model addresses all of these issues to see whether productivity differences can account for the observed evolution of economic structure along the development path within a general equilibrium framework. See the Appendix.

3 Evidence

In this section we provide some evidence in support of the key mechanisms in the paper.

3.1 Productivity and structural change

As noted, the quantitative theory has two strong predictions:

1. within manufacturing, as countries develop they shift resources towards high-TFP growth industries;
2. in contrast, across broad sectors, as countries develop they shift resources towards low-TFP growth sectors.

To test whether the data support these predictions, we compute a time series for the weighted average g_i in manufacturing and (separately) across sectors for each country and at each date. For manufacturing, we normalize g_i so that the mean measure is zero and the standard deviation is one. Then, for each country at each date, we compute the weighted average TFP growth measure, where the weights are the value added shares of each industry in total manufacturing, computed using UNIDO data. Finally, we examine the empirical relationship between average manufacturing TFP growth and GDP per capita, by applying the nonparametric method in IW to this measure instead of to the Gini coefficient of industry shares. TFP growth rates are assumed constant in each industry across time and across countries, so any patterns are solely due to patterns of specialization along the development path. We follow the same procedure for the sector shares reported in the ILO data.

Figure 6 shows the estimated curves of industry- and sector-weighted average TFP growth rates. Within manufacturing, there is a mostly positive relationship with income, indicating that, behind the "stages of diversification", economic structure shifts towards industries with rapid TFP growth, as predicted by the model.²⁶ In the ILO sector data, by contrast, there is a negative relationship, consistent with the finding that $\varepsilon < 1$. These results strongly support the assumption that TFP growth differences can be a driving force behind structural change along the development path, and it is striking that the opposite is happening within manufacturing and across broad sectors.

²⁶We use the g_i measure based on NBER data. Results with g_i^{median} , as well as the UNIDO-based measures of g_i , are similar.

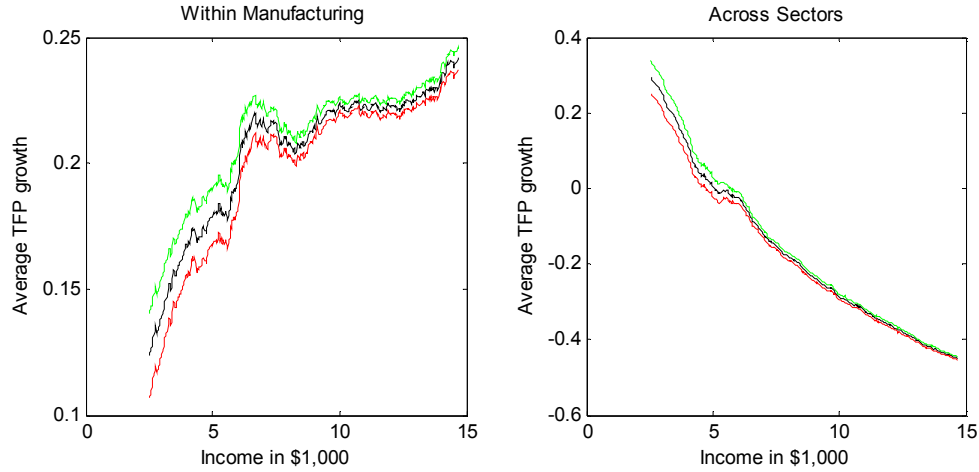


Figure 6 – Trends in average TFP growth within manufacturing and across sectors along the development path. The middle line is the point estimate, whereas the other lines reflect the point estimate plus or minus the standard error of $\hat{\beta}(x)$, as in IW.

Another way of testing these predictions is to examine directly whether changes in the shares of individual industries change along the development path are systematically related to g_i . Specifically, within manufacturing, we should observe that the share of the highest-TFP growth industry (Non-electrical machinery) rises steeply with income per head, whereas the share of the lowest-TFP growth industry (Tobacco) declines steeply with income per head. Figure 7 shows that this is exactly the case, where the curves are estimated using the IW method. More broadly, comparing across all industries in manufacturing, we expect the slope of the relationship between industry shares and GDP to be *positively* related to g_i . Indeed, the correlation between the slopes and g_i is 0.60, significant at the 5 percent level. On the other hand, across *sectors*, the slope of the relationship between sector shares and GDP should be *negatively* related to g_i . The correlation coefficient is -0.65 , significant at the 10 percent level.

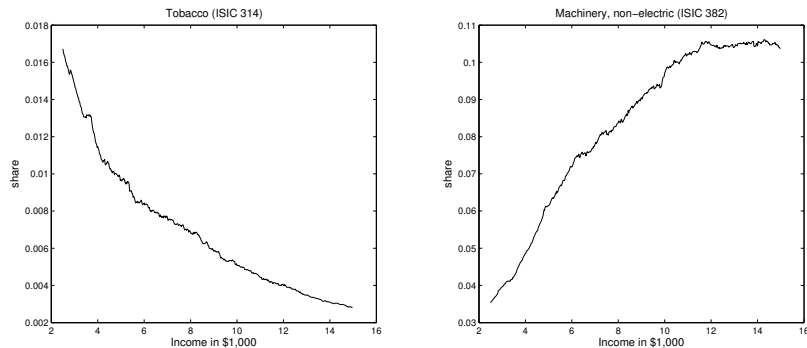


Figure 7 – Trends in industry shares along the development path. The curves represent the link between industry shares and income per head for the highest- and lowest-TFP growth industries, Non-electrical Machinery and Tobacco, computed using the IW methodology.

3.2 Other factors of structural change

We have focused on productivity differences as the factor that drives structural change. However, there are other theories of long-run structural change that imply a shift in resources towards particular industries in the long run. As long as countries begin specialized in industries other than those that dominate in the long run, those models too might predict stages of diversification.

At least four general equilibrium frameworks have recently been developed to think about long-term structural change:²⁷

1. Ngai and Pissarides (2007, NP) emphasize persistent productivity differences across industries, as we do.

²⁷In addition, Kongsamut et al (2000) relate structural change to differences in requirements for different goods – so that, for example, instead of utility over consumption of good i being defined over c_i , it is defined over $c_i - \bar{c}_i$, where $\bar{c}_i > 0$ is a constant. We do not think of this account of structural change as being relevant for the "stages" because $\bar{c}_i$ is generally interpreted in terms of requirements for agricultural goods, something that is not obviously relevant for disaggregated manufacturing industries. At the sector level, we have 9 sectors, so again requirements would likely be relevant for at most one sector.

2. Ilyina and Samaniego (2012, IS) emphasize productivity differences driven by differences in desired R&D intensity. This theory is not at odds with that of NP, but digs deeper as to the underlying causes of TFP growth differences.
3. Acemoglu and Guerrieri (2008, AG) consider both productivity differences and differences in capital shares. Specifically they predict that TFP growth rates divided by labor shares determine which industries tend to dominate in the long run.
4. Buera and Kaboski (2012) argue that structural change is affected by industry differences in firm size, with poorer countries less able to afford large-scale technologies.

To see whether structural change appears related to any of the factors of structural change other than TFP growth rates (R&D intensity, labor intensity, firm size), we repeat the experiment illustrated in Figure 6 and compute series for the weighted average of each of these measures (R&D intensity, etc.) for each country over time. Industry R&D intensity and labor intensity measures are 3-decade averages of the values reported in Ilyina and Samaniego (2011).²⁸ The industry firm size is the average number of employees per establishment in the US over the period 1963-1992, as reported by UNIDO in INDSTAT3. Again, each measure is normalized so that the mean measure is zero and the standard deviation is one. Then, as before, weighted averages are computed for each country-year, where the weights are value added shares of each industry in total manufacturing, computed using UNIDO data. Finally, we apply the same nonparametric method to these measures, examining their relationship to real GDP per capita.

Figure 8 shows the estimated curve (nonparametric) for each of these measures. Average R&D displays a positive relationship with income within manufacturing, indicating that, behind the "stages of diversification", economic structure shifts towards industries with rapid TFP growth, and industries with high R&D intensity. Figure 8 also shows the same for the broad sectors in the ILO data:²⁹ in this case the trend is downwards, consistent with the assumption that $\varepsilon < 1$. These results support the assumption that TFP growth differences can be a driving force behind structure change along the development path, and that TFP growth is related to R&D intensity.

Regarding the other measures, AG argue that differences in labor shares could be a driving force behind structural change. We also report the estimated curve (nonparametric) of the

²⁸R&D intensity is the median R&D spending as a share of capital expenditures among firms in Compustat. Labor intensity is the wage share of value added in the INDSTAT3 database.

²⁹For most measures, unfortunately we do not have data for sectors outside of manufacturing.

weighted average labor intensity in the manufacturing sector. We can see that labor intensity shows a hump-shaped relationship with income. In particular, labor intensity declines beyond the income level of \$10,000. Thus, while labor shares may be a factor of structural change, they do not appear to play a consistent role throughout the "stages".³⁰ This justifies our focus on a model with productivity differences, abstracting from differences in labor shares. As for firm size, average firm size declines along the development path before flattening out, which does not obviously support the idea that countries are more able to overcome large optimal scales of production as they develop.³¹ Again, this does not mean that the scale of production is not relevant for understanding some aspects of economic structure (e.g. the Buera and Kaboski (2012) model is about resource shifts between the home and the market), but it is not obviously related to the "stages."

³⁰More specifically, AG argue that the relevant variable is the productivity growth rate divided by the labor share. The weighted average of this variable across manufacturing industries behaves in a manner similar to the labor share.

³¹This result, however, is consistent with high TFP growth industries having a relatively small firm size, as found by Mitchell (2002).

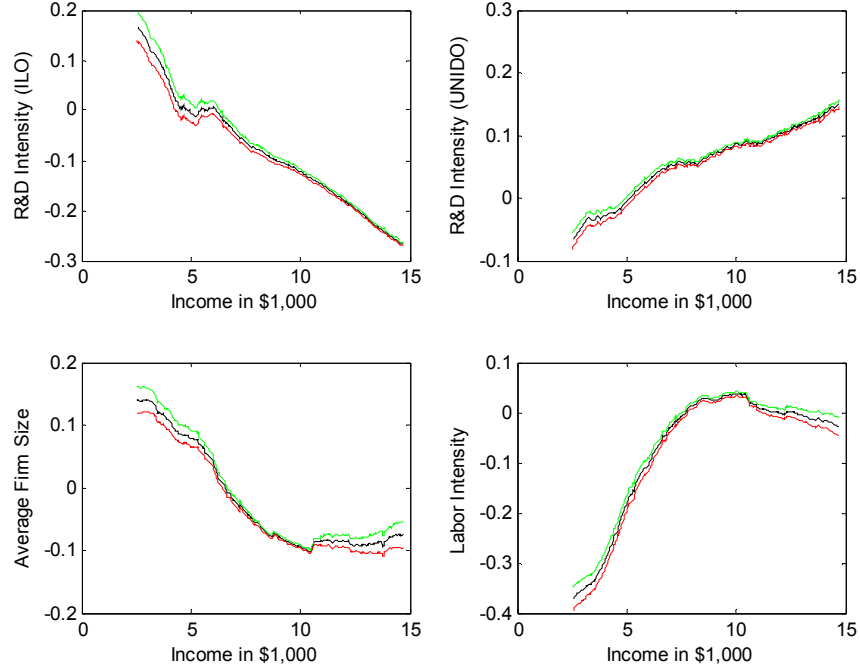


Figure 8 – Trends in average firm size, R&D intensity and labor intensity within manufacturing along the development path. The pattern of R&D intensity is consistent with TFP growth being related to R&D spending.

The other measures do not display a monotonic relationship with income.

4 Concluding Remarks

We develop a multi-sector model in which differential TFP growth rates across industries and sectors lead to structural change along an unbalanced growth path. We find that the model accounts for the pattern of diversification followed by specialization – stages of diversification – that is well-known in the literature. The results are robust to a variety of extensions and modifications, and hold both across sectors and within manufacturing. We do not exclude other possible factors, such as differences in factor shares (as in AG) or international trade (as in IW). However, the paper provides quantitative evidence that productivity differences can account on their own for the dynamics of industrial structure along the development path.

IW attribute the U-shaped "stages" to the interaction of aggregate income and openness to trade, and in general the literature tends to interpret the "stages" as being related to

trade.³² However, this does not explain why a closed economy model displays a U-shaped pattern of specialization. Indeed, before concluding that international trade is an important determinant of the evolution of economic structure along the development path, we need to understand how economic structure would evolve under autarky. This paper shows that even in a closed economy persistent total factor productivity (TFP) growth differences across industries are sufficient to generate a U-shaped pattern of specialization. It would be interesting in future work to develop a model that nests all the various possibilities, to estimate the contribution of different factors to the evolution of economic structure. Also, IW find that open economies tend to re-specialize at a lower income level, something that would be interesting to study in an open-economy version of the model.

The results suggest that a productivity driven theory can account for both income levels and economic structure. This lends further emphasis to the question of the ultimate determinants of productivity growth rates. Ngai and Samaniego (2011) relate productivity growth rates to the technological determinants of R&D intensity and Ilyina and Samaniego (2012) are able to account for country *differences* in industry growth rates based on an interaction of research intensity and institutional frictions, suggesting fruitful avenues for future research.

An additional prediction of the model is that, as countries grow, the relative price of capital should be observed to decline. The reason is that wealthier countries devote increasing resources towards the production of capital goods with relative high TFP growth rates, whereas much of the rest of the economy is shifting resources towards low-TFP growth goods and services. TFP in the production of capital goods grows faster than in the rest of the economy, leading the price of capital to decline over time as economies grow. Hsieh and Klenow (2007) note that the link between the high relative price of capital and relative prosperity is an important stylized fact of development economics, and the model suggests an account for this phenomenon based on productivity-driven structural change. An exploration of this topic is left for future work.

Similarly, the prediction that the composition of capital shifts towards the most high-tech industries provides an explanation for the observed acceleration of investment-specific technical progress in the US (typically measured using the relative price of capital). Krusell et al (2000) relate this to increasing wage inequality, and it would be interesting more broadly to understand the link between economic structure and wage inequality.

In the paper we take initial conditions as given for our quantitative experiments. The results suggest that poorer countries tend to begin specialized in industries where TFP

³²See for example Kalemli-Ozcan, Sorensen and Yosha (2003) or Rodrik (2008).

growth is low. Although it is beyond the scope of this paper, it is interesting to think about why initial conditions might be biased in this way. One possibility is that there are non-homothetic preferences (see Kongsamut et al (2000)), so that consumption patterns in poor countries are dominated by subsistence considerations that wear off later. If manufacturing industries that produce goods necessary for subsistence (e.g. food products) happen to have slow TFP growth, whereas sectors that are necessary for subsistence (e.g. agriculture) so happen to have rapid TFP growth, then we would observe these initial conditions. Another possibility that does not hinge on non-homothetic preferences involves the transition from a "traditional" technology with low productivity growth to a "modern" technology with more rapid productivity growth. Ngai (2004) shows that small differences across countries in barriers to technology adoption can lead to very large differences in income by delaying the transition from the "traditional" to the "modern" technologies. Initial conditions would be determined by the traditional technology and the date of transition between technologies. The idea that the transition between the "traditional" and "modern" technologies could explain historical economic structure as well as income levels is an interesting topic for future research.

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Appendix

A General equilibrium model

We now develop a multi-industry growth model and ask whether the mechanisms described above can generate stages of diversification at the industry or sector levels in this environment in a general equilibrium framework.

A.1 Preferences and Technology

Time is discrete and there is a $[0, 1]$ continuum of agents. There are S sectors, each of which produces an aggregate of I industries. Let I_s be the set of industries that supplies sector s . We focus on the case in which each industry supplies only one sector, so that $I_s \cap I_{s'} = \emptyset$, $\forall s \neq s'$. Note that this is without loss of generality, as one could have two industries identical in all ways that are distinguished by the fact that they provide a given good to two different sectors.

We assume that sectors $s \in \{1, \dots, S-1\}$ produce consumption goods. Only one sector, S , produces capital goods. Now for each sector $s \in \{1, \dots, S\}$, the production function has the CES form:

$$y_{st} = \left[\sum_{i \in I_s} \xi_i \times u_{s,i,t}^{\frac{\varepsilon_s-1}{\varepsilon_s}} \right]^{\frac{\varepsilon_s}{\varepsilon_s-1}}, \quad \sum_{i \in I_s} \xi_i = 1, \quad s = 1, \dots, S \quad (9)$$

where u_{sit} is use of good i by sector s , ξ_i is the weight on good i , and ε_s is the elasticity of substitution among goods within sector s .

Agents consume a CES aggregate c_t of the output of the different consumption sectors:

$$c_t = \left[\sum_{s=1}^{S-1} \zeta_s y_{st}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}.$$

Finally, agents have isoelastic preferences over c_t and discount the future using a factor $\beta < 1$, so that:

$$\sum_{t=0}^{\infty} \beta^t \frac{c_t^{1-\theta} - 1}{1-\theta}. \quad (10)$$

They are endowed with one unit of labor every period which they supply inelastically, and start period zero with capital K_0 .

Let q_{st} be the price of the sector aggregate s , with r_t as the interest rate and w_t as the wage. Agents choose expenditure on each good so as to maximize (10) subject to the budget constraint

$$\sum_{s=1}^S q_{st} y_{st} \leq \sum_{s=1}^S \sum_{i \in I_s} r_t K_{it} + \sum_{s=1}^S \sum_{i \in I_s} w_t n_{it} \quad (11)$$

and the capital accumulation equation

$$K_{t+1} = y_{St} + (1 - \delta) K_t. \quad (12)$$

On the supply side, each industry features a Cobb-Douglas production function:

$$y_{it} = A_{it} K_{it}^\alpha n_{it}^{1-\alpha}, \quad A_{it} = A_{i0} g_i^t \quad (13)$$

where $g_i = A_{i,t+1}/A_{it}$ is the TFP growth factor of industry i and A_{i0} is given. Producers maximize profits

$$\max_{n_{it}, K_{it}} \{p_{it} y_{it} - w_t n_{it} - r_t K_{it}\} \quad (14)$$

subject to (13), where p_{it} is the output price of industry i at time t . Capital and labor are freely mobile across sectors – we discuss this assumption further in Section G .

A.2 Equilibrium

The producers' first order conditions imply that the capital labor ratio is constant across industries, which implies that $A_{it} p_{it} = A_{jt} p_{jt}$. Thus, as in related models, goods that experience rapid productivity growth display a decline in their relative price. This result, combined with the consumer's first order conditions implies that the ratio of value added $p_{it} y_{it}$ in any two industries in the same sector s depends on parameters and the productivity terms.

$$\frac{p_{it} y_{it}}{p_{jt} y_{jt}} = \left(\frac{\xi_{s,i}}{\xi_{s,j}} \right)^{\varepsilon_s} \left(\frac{A_{it}}{A_{jt}} \right)^{\varepsilon_s - 1} = \frac{n_{it}}{n_{jt}} \quad \forall s \quad (15)$$

Notice that the same relationship holds for the ratio of employment – just as with the basic model – except that it only holds comparing industries that are in the same sector.

Define the growth factor of employment (or value added) in industry i as

$$G_{it} \equiv \frac{n_{i,t+1}}{n_{i,t}} = \frac{p_{i,t+1} y_{i,t+1}}{p_{it} y_{it}}. \quad (16)$$

Then, the expression G_{it}/G_{jt} then denotes the growth of employment (or value added) in industry i relative to industry j . Using (15) we have that

$$\frac{G_{it}}{G_{jt}} = \left(\frac{g_i}{g_j} \right)^{\varepsilon_s - 1} \quad \forall s. \quad (17)$$

Consequently, within sectors, structural change depends on relative TFP growth factors $\frac{g_i}{g_j}$ and on the elasticity of substitution ε_s . For comparing industries *across* sectors requires characterizing shifts in expenditure across sectors, as well as investment behavior.

A.3 Sectorial and Aggregate Growth

Notice that in equilibrium we can aggregate the industries in a given sector into a sectorial production function. To see this, define q_{st} as the price index for final goods in sector s , so that

$$q_{st}y_{st} = \sum_{i \in I_s} p_{it} A_{it} k_t^\alpha n_{it}$$

where k_t is the equilibrium capital-labor ratio, which is common across industries. Define input use in sector s as $K_{st} = \sum_{i \in I_s} K_{it}$ and $n_{st} = \sum_{i \in I_s} n_{it}$. Then, define a sectorial production function:

$$y_{st} = A_{st} K_{st}^\alpha n_{st}^{1-\alpha}, \quad A_{st} = A_{s0} \bar{g}_s^t \quad (18)$$

where $\bar{g}_{st} = A_{s,t+1}/A_{st}$.

The problem of the sector s firms and the industry $i \in I_s$ firms can be combined as

$$\max_{n_{it}} \left\{ q_{st} \left[\sum_{i \in I_s} \xi_i \times (A_{it} k_t^\alpha n_{it})^{\frac{\varepsilon_s - 1}{\varepsilon_s}} \right]^{\frac{\varepsilon_s}{\varepsilon_s - 1}} - r_t k_t \sum n_{it} - w_t \sum n_{it} \right\} \quad (19)$$

The first order conditions imply that:

$$\frac{n_{jt}}{n_{it}} = \left(\frac{\xi_j}{\xi_i} \right)^{\varepsilon_s} \left(\frac{A_{it}}{A_{jt}} \right)^{1-\varepsilon_s} \quad (20)$$

We also have that $\sum_i n_i = n_s$ by definition, so we can use (20) write n_i in terms of n_s . Substituting this back into problem (19), we have that a sector s firm solves the problem

$$\max_{n_{it}} \{ q_{st} A_{st} k_t^\alpha n_s - r k n_{st} - w n_{st} \}$$

where

$$A_{st} = \left[\sum_{i \in I} \xi_{s,i}^{\varepsilon_s} \times A_{it}^{\varepsilon_s - 1} \right]^{\frac{1}{\varepsilon_s - 1}} = \left[\sum_{i \in I} \xi_{s,i}^{\varepsilon_s} \times A_{i0}^{\varepsilon_s - 1} g_i^{t(\varepsilon_s - 1)} \right]^{\frac{1}{\varepsilon_s - 1}}. \quad (21)$$

Recalling that $\bar{g}_{st} = A_{s,t+1}/A_{st}$, we have that

$$\bar{g}_{st} = \prod_{i \in I_s} g_i^{x_{it}/X_{st}} \quad (22)$$

where

$$x_{it} = \xi_{s,i}^{\varepsilon_s} A_{it}^{\varepsilon_s - 1}, \quad X_{st} = \sum_{i \in I_s} x_{it}.$$

Since the total production of consumption sectors $c_t = \left[\sum_{s=1}^{S-1} \zeta_s y_{st}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}$, we can also aggregate all the consumption goods production sectors in the same fashion. Then we have that

$$c_t = A_{c_t} K_{c_t}^\alpha n_{c_t}^{1-\alpha}, \quad A_{c_t} = \left[\sum_{s=1}^{S-1} \zeta_s^\varepsilon \times A_{st}^{\varepsilon-1} \right]^{\frac{1}{\varepsilon-1}} \quad (23)$$

As a result, the aggregate behavior of the model economy with many sectors is the same as that of a 2-sector economy that produces c_t using technology (23) and produces capital goods using technology (18). In the consumption goods sector, firms maximize

$$\begin{aligned} & \max_{K_{c_t}, n_{c_t}} \{ p_{c_t} A_{c_t} K_{c_t}^\alpha n_{c_t}^{1-\alpha} - r_t K_{c_t} - w_t n_{c_t} \} \\ \text{where} \quad A_{c_t} &= \left[\sum_{s=1}^{S-1} \zeta_s^\varepsilon \times A_{st}^{\varepsilon-1} \right]^{\frac{1}{\varepsilon-1}} \end{aligned}$$

whereas in the capital goods sector:

$$\begin{aligned} & \max_{K_{h_t}, n_{h_t}} \{ p_{S_t} A_{S_t} K_{S_t}^\alpha n_{S_t}^{1-\alpha} - r_t K_{S_t} - w_t n_{S_t} \} \\ \text{where} \quad A_{S_t} &= \left[\sum_{i \in I_S} \xi_i^{\varepsilon_S} \times A_{it}^{\varepsilon_S-1} \right]^{\frac{1}{\varepsilon_S-1}} \end{aligned}$$

Consumers choose consumption c_t and investment y_{S_t} to solve:

$$\max_{c_t, h_t} \left\{ \sum_{t=0}^{\infty} \beta^t \frac{c_t^{1-\theta} - 1}{1-\theta} \right\} \quad (24)$$

$$s.t. \quad p_{c_t} c_t + p_{S_t} y_{S_t} \leq r_t K_t + w_t \quad (25)$$

$$K_{t+1} = K_t (1 - \delta) + y_{S_t} \quad (26)$$

$$K_0 \text{ given.} \quad (27)$$

In equilibrium, capital and labor markets must clear at all dates, so

$$c_t = A_{c_t} K_{c_t}^\alpha n_{c_t}^{1-\alpha} \quad (28)$$

$$y_{S_t} = A_{S_t} K_{S_t}^\alpha n_{S_t}^{1-\alpha}$$

$$K_t = K_{S_t} + K_{c_t} \quad (29)$$

$$n_{c_t} + n_{S_t} = 1 \quad (30)$$

It will be convenient to set $p_{S,t} = 1 \forall t$, so that consumption goods prices p_{c_t} are expressed relative price to the price of capital goods.

Solving the 2-sector problem and using the equilibrium conditions, we obtain expressions for labor shares in the capital goods sector n_{St} and the consumption goods' sector $n_{ct} = 1 - n_{St}$ along an unbalanced growth path. These turn out to be functions only of the productivity growth rates g_i , parameters, and of the equilibrium growth rate of aggregate consumption $g_{ct} = \frac{p_{ct,t+1}c_{t+1}}{p_{ct}c_t}$ which is endogenous. This will be true at all dates except possibly date zero, where n_{St} is determined by the initial condition K_0 .

Define real GDP as $y_t = y_{St} + p_{ct}c_t$. Notice it is measured in units of capital.

Proposition 1 *Equilibrium exists and is unique. In equilibrium, the growth factors of total capital K , capital per capita k , and total output y depend on the growth factors of TFP in the consumption and capital sectors and on the growth factor of consumption sector (as well as parameters):*

$$g_{k_t} = \frac{k_{t+1}}{k_t} = \frac{K_{t+1}}{K_t} = \bar{g}_{A_{St}}^{\frac{1}{1-\alpha}} \left(\frac{r_t}{r_{t+1}} \right)^{\frac{1}{1-\alpha}} \quad (31)$$

and

$$g_{y_t} = \frac{y_{t+1}}{y_t} = \bar{g}_{A_{St}}^{\frac{1}{1-\alpha}} \left(\frac{r_t}{r_{t+1}} \right)^{\frac{\alpha}{1-\alpha}} \quad (32)$$

where GDP is defined as $y_t = y_{St} + p_{ct}c_t$ and the equilibrium interest rate is $r_t = \frac{\left(\frac{\bar{g}_{A_{St-1}}}{\bar{g}_{A_{ct-1}}} \right)^{1-\theta} g_{ct-1}^\theta}{\beta} - 1 + \delta$ for $t > 0$. At date zero, r_0 is determined by market clearing given K_0 .

Proposition 2 *The model economy converges to a balanced growth path where in each sector*

$$\lim_{t \rightarrow \infty} A_{st} = A_{jt} \text{ where } j = \begin{cases} \arg \max_{i \in I_s} \{A_i\} & \text{if } \varepsilon_s > 1 \\ \arg \min_{i \in I_s} \{A_i\} & \text{if } \varepsilon_s < 1 \end{cases},$$

and

$$\lim_{t \rightarrow \infty} A_{ct} = A_{st} \text{ where } s = \begin{cases} \arg \max_{s < S} \{A_s\} & \text{if } \varepsilon > 1 \\ \arg \min_{s < S} \{A_s\} & \text{if } \varepsilon < 1 \end{cases}.$$

Recalling that the only endogenous variable that affects r_t for $t > 0$ is g_{ct} ,³³ Proposition 1 implies that we can compute the equilibrium for the multi-industry model economy in transition, provided we can derive the series for g_{ct} . The economy with many consumption goods sectors will asymptotically converge to an economy with one consumption sector which has either the highest or lowest TFP growth rate depending on the elasticity of substitution. The same occurs within the capital goods sector. As a result, the expression r_t converges to some constant r and, although in general the model does not possess a balanced growth path

³³In general, at $t = 0$, the value of r_0 is determined by market clearing and the value of K_0 .

(see Ngai and Pissarides (2007)), it converges to one. This suggests that the equilibrium may be computed by finding a sufficiently good approximation to the series for g_{ct} . In the limit, since by assumption $\varepsilon_s \neq 1$ for all $s \leq S$, one industry will end up dominating each sector. However, we wish to study the behavior of the model economy in transition, where sectors are relatively diversified.

B UNIDO Calibration: Manufacturing

In the remainder of the paper we will focus on a particular type of equilibrium. Observe that the capital stock will be set to satisfy the Euler equation (31) at all dates except date zero. In other words, the investment share of the model economy will in general be smooth over time, except between dates zero and one. The model will be calibrated to the available data and, since the initial year in which data for a given country become available has no economic content, it is difficult to justify why the first year we have data for (generally 1963) happens to be the only date when the intertemporal optimization condition (31) is not satisfied. For this reason, we focus on an equilibrium where this does not occur.

Definition 3 *An Euler Growth Path (EGP) is an equilibrium and an initial condition K_0 such that equation (31) holds at date zero.*

The Euler growth path is a generalization of a balanced growth path which exists in models that do not exhibit balanced growth. For our benchmark results, we calibrate the model to match an Euler growth path by matching the composition of manufacturing but not necessarily its *size*. Details are in Section D. Nonetheless, it is important to underline that our results concerning the structure of the economy turn out not to hinge on whether we focus on an Euler growth path: results on the equilibrium calibrated to match the initial conditions in the data are qualitatively indistinguishable.

Calibrating the model economy requires a choice of industries, and values of the following parameters and variables.

1. Technological parameters α, δ .
2. Preference coefficients $\xi_{s,i}, \zeta_i, \beta$.
3. Elasticities of substitution ε_s for $s \leq S$, and ε , the elasticity across consumption sectors
4. The intertemporal elasticity parameter θ .

Table 1: Sectors and Industries in the model economy

Sector	Industries			
	Agriculture	Services, etc	ISIC Manuf	Construction
Agriculture	X	-	-	-
Services, etc	-	X	-	-
Manufacturing (not capital)	-	-	X	-
Manufacturing (capital)	-	-	X	X

5. Productivity growth values g_i .

6. Productivity initial conditions A_{i0} .

We provide two selections of industries. In this section, we calibrate the model so as to focus on the "stages" in manufacturing in the UNIDO data. In the following section, we disaggregate the non-manufacturing sectors further to focus on the "stages" across broad sectors in the ILO data. We calibrate the model twice because the data required for the ILO sector calibration are available for fewer countries. We refer to them as the UNIDO or manufacturing calibration and the ILO or sector calibration. Details are provided below. The simulation requires computing transition dynamics in a model without a balanced growth path, and the procedure is described in Section *D*.

For the UNIDO calibration, we group all industries into four sectors: Agriculture, Services, Capital and Non-capital manufacturing. Agriculture, services and non-capital manufacturing sectors produce consumption goods, and the capital sector only produces capital goods. Industries include agriculture, services, the 28 UNIDO manufacturing industries, and construction (see Table 1). Thus, the agriculture and services industries only contain one industry. The UNIDO industries serve either the capital or the non-capital manufacturing sectors. We assigned an industry to the capital sector if the US NIPA tables count it in their "fixed asset" tables (see Table 2). Construction serves the capital sector too. The initial shares of agriculture, services, manufacturing and construction sectors out of GDP are derived from World Development Indicators data (WDI).³⁴

³⁴For countries with missing data, we use predicted values computed by regressing sector shares on income, income squared and UNIDO industry shares in the manufacturing sector for all countries and years in our sample.

Table 2: Capital good-producing manufacturing industries

Industry	ISIC code
Wood products	331
Furniture, except metal	332
Fabricated metal products	381
Machinery, except electrical	382
Machinery, electric	383
Transport equipment	384
Prof. & sci. equip.	385
Other manufactured prod.	390

1. We assume that $\delta = 0.06$ as in Greenwood et al (1997): this is a standard values in models in which the productivity of the investment technology exceeds that in the consumption sector. We use a standard value for the capital share, $\alpha = 0.3$.
2. To calibrate the utility weights $\xi_{s,i}$, it should be noted that in a sense these weights are arbitrary, as they depend on the exact unit of measurement for good i .³⁵ Thus, without loss of generality, we set $\xi_{s,i} = \frac{1}{I_s}$, where I_s is the number of industries in sector s . The same applies to ζ_i , the utility weight at the sector level, so $\zeta_i = \frac{1}{S-1}$. We set $\beta = 0.95$, a standard value.
3. For each sector, equation (17) is equivalent to $\log G_i = \alpha + (\varepsilon - 1) \log g_i + \epsilon_i$ where $\alpha = \log G_j - \log g_j$ for some arbitrary industry j and ϵ_i is any unmodeled noise in the relationship. We regress U.S. value added growth rates on TFP growth rates³⁶ for capital and non-capital manufacturing goods respectively, finding that they were not statistically significantly different: $\varepsilon_{noncapmanuf} = \varepsilon_{capital}$. Pooling the data, we estimate that $\varepsilon_{noncapmanuf} = \varepsilon_{capital} = 3.73$. Across sectors, we use the value $\varepsilon = 0$, as

³⁵For example, if I measure apples and get $\xi_{s,apples} = 2$ (and $A_{apples,0} = 3$), I could choose to measure apples in units of "half an apple" and then $\xi_{s,apples} = 1$ (and $A_{apples,0} = 1.5$).

³⁶We use data from Jorgenson et al (2007): although they are a little more disaggregated, we want a value estimated at roughly the same level of aggregation as the UNIDO data. The UNIDO data themselves are too few so we were unable to obtain a good estimate from them directly. The estimate of ε is slightly different from Ilyina and Samaniego (2012) because of the inclusion of Construction in the set of capital goods producing industries.

discussed earlier.

4. The preference parameter θ is calibrated so that in the long run the investment share of GDP converges to 12 percent, which is roughly the share in the US: investment shares in transition turn out not to be very different. This implies that $\theta = 3$: typical values used in calibration fall in the range $\theta \in [1, 5]$,³⁷ so it is encouraging that our value falls in the middle.
5. Productivity growth values g_i are drawn from the NBER productivity database, as described in Section 2. We use the average value over the period 1963-1992. See Table 4. To calibrate the growth factors of the consumption goods sectors, first we use equation (21) to compute TFP growth in the capital sector (excluding construction) over the period 1963-1992, and get the average value $g_S = 1.0241$. According to NIPA, the relative price of construction has risen at a rate of 0.0109 each year relative to other capital. This means the growth factor of construction sector $g_{construction} = g_S/e^{0.0109} = 1.0130$. For the services sector, the relative price of services has risen at a rate of 0.0103 each year relative to other capital. This means the growth factor of services sector $g_{services}$ is then $g_S/e^{0.0103} = 1.0136$. For agriculture, we have that the relative price of agriculture has dropped at a rate of 0.004 each year relative to other capital. So the growth factor of the agricultural sector is $g_{agriculture} = g_S/e^{-0.004} = 1.0282$.
6. For the initial productivities of the capital and consumption sectors, we initially set $A_{capital,0} = 1$ and $A_{consumption,0} = 1$. The former is a normalization, and the latter is without loss of generality because the size of the non-investment sectors is independent of the level of $A_{consumption,0} = 1$.³⁸ Then, using (15) and (21), for the capital sector industries $i \in I_S$, we set initial TFP to equal $A_{i0} = \left[\frac{n_{i0}}{\sum \xi_i^{\varepsilon_S} n_{i0}} \right]^{\frac{1}{\varepsilon_S - 1}}$, thus matching the initial share of capital industries in each country. For the consumption sectors, set A_{s0} (where $s \in \{\text{services, agriculture and non-capital manufacturing}\}$) so as to match the initial share of that sector in each country: $A_{s0} = \left[\frac{n_{s0}}{\sum \xi_s^{\varepsilon} n_{s0}} \right]^{\frac{1}{\varepsilon - 1}}$. Finally, for industry productivity in non-capital manufacturing, we have again that $A_{i0} = \left[\frac{n_{i0} A_{s0}}{\sum \xi_i^{\varepsilon_S} n_i} \right]^{\frac{1}{\varepsilon_S - 1}}$.

³⁷Growth models tend to use $\theta = 1$, whereas asset pricing studies tend to use larger values, see for example Jermann (1998).

³⁸Proof available upon request. We could calibrate the ratio of these productivity terms to match the relative price of capital reported in the initial year in the Penn World Tables 7.1 but this does not affect results – as a result of the Proposition.

Table 3: Calibrated Parameters: Baseline Model

$\mathcal{G}_{construction}$	$\mathcal{G}_{services}$	$\mathcal{G}_{agriculture}$	$\varepsilon_{capital}$	$\varepsilon_{consumption}$
1.0130	1.0136	1.0282	3.73	0
$\varepsilon_{noncapmanuf}$	θ	δ	α	β
3.73	3	0.06	0.3	0.95

Industry shares are drawn from UNIDO and sector shares are based on the WDI.³⁹ Finally, we multiply A_{i0} in all industries and sectors by a country-specific constant so that the country GDP per head relative to US GDP per head in the initial year is the same as in the data.

Finally, there are many country factors the literature has related to economic growth which are not featured in the model (see for example Barro (1991) or Sala-i-Martin (1997)). We add a country-specific productivity growth term that affects all industries equally, and calibrate it to match average GDP growth rates in each country over the sample period. This term could be interpreted as capturing policies that affect technological diffusion, trends in policy, or any of the factors commonly included in growth regressions. In any case, results are not sensitive to the inclusion of this term.

B.1 Simulation

For each country we use initial conditions from 1963⁴⁰ as starting points, and simulate the share of GDP n_{it} of any industry or sector along unbalanced growth path.⁴¹

³⁹As mentioned, an adjustment to industry shares is required due to our focus on an EGP: see Section D for details.

⁴⁰For some countries initial data in 1963 are not available: then we use the earliest available year.

⁴¹In our derivations, the model measures GDP in terms of capital goods (remember we normalize capital goods price to 1 and consumption goods prices are expressed as relative to capital goods price). In the data, however, GDP is measured in terms of consumption goods, see Greenwood et al (1997). Since in our model, $A_{h_t} = p_{c_t} A_{c_t}$, we can express the GDP growth factor measured in units of *consumption* using the formula $\tilde{g}_{yt} = g_{yt} \frac{g_{Ah}}{g_{Ac}}$. This is the notion of GDP we use in the graphs below. The model simulated using GDP defined in terms of capital goods yields very similar results. An issue here is that the values of A_{h_0} and A_{c_0} are arbitrary in the calibration, but not when we wish to express cross-country GDP in common

Figure 9 shows the estimated curve of Gini using industry shares simulated in our baseline model. We can see that our baseline model is able to capture the U-shape of stages of diversification very well. Thus, the results derived using the simple model are robust to allowing the composition and size of the capital sector to evolve independently of the non-capital manufacturing sector, and to allowing the model to generate the GDP series as well as just industry structure. It is notable that, in the full growth model, the re-specialization after the turning point is slower than the initial specialization, just as in IW.⁴²

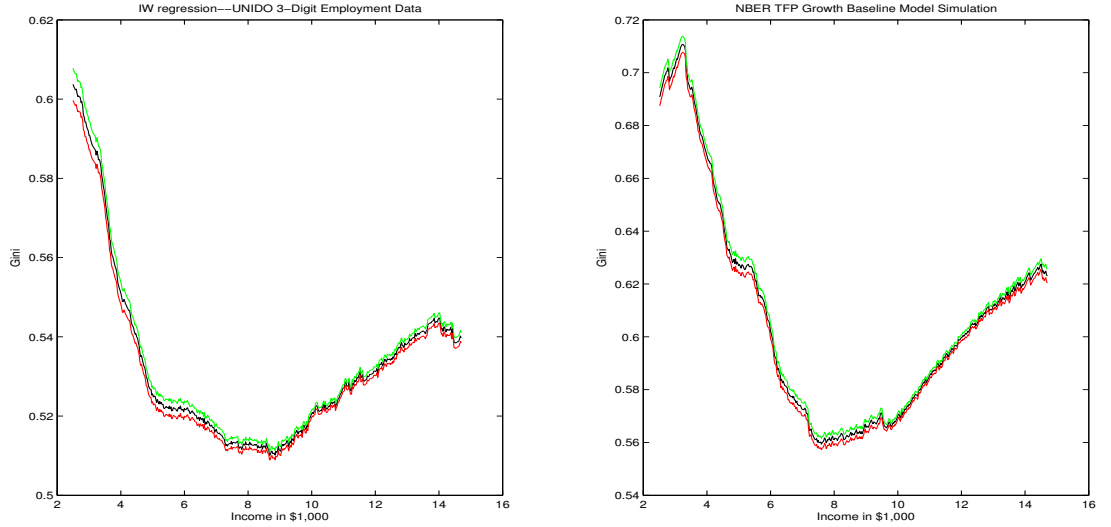


Figure 9. Industry structure along the development path in the full model. The left panel is the relationship between income and specialization within manufacturing reported in IW. The right panel is the same relationship in the pseudo-data generated from the model economy. The range of income is the same as that reported in IW.

C ILO Calibration: Broad sectors

IW report how economic structure evolves along the development path for 9 broad sectors, drawing on data from the ILO. In this section, we will show that TFP growth differences in units. We handle this by assuming that the real GDP data are measured in units of consumption and are internationally comparable, and then use the model to compute growth rates (which do not depend on GDP levels) extrapolating from initial GDP in the data.

⁴²If we extend the simulated curve from \$15,000 to \$20,000, the rising right hand side of the curve continues to increase linearly.

our model can explain economic structure through the economy at sector level. We recalibrate the model economy so that $S = 10$, where the capital and non-capital manufacturing sectors are the same as in the UNIDO calibration, whereas the other 8 sectors correspond to the non-manufacturing sectors in the ILO 1-digit data. Thus, whereas before we had capital, non-capital manufacturing, agriculture and services, we now disaggregate services into several new sectors. See Table 5 for the list of non-manufacturing sectors. Within manufacturing, we still use 28 UNIDO industries, of which 8 produce capital goods as the UNIDO calibration (Table 2). The definition of the capital goods sector is the same as the UNIDO calibration, i.e. 8 UNIDO industries and construction. All other sectors in Table 5 produce consumption goods. The initial sector shares are taken from the ILO dataset.⁴³ As earlier, we set $\varepsilon = 0$. All other parameters are calibrated as before.

Figure 10 shows the estimated link between income and sectoral concentration using the 9 ILO sector shares simulated in our model. It is clear that economic structure at sector level still displays a U-shape. Again, the turning point is around \$9,000 as in the data.

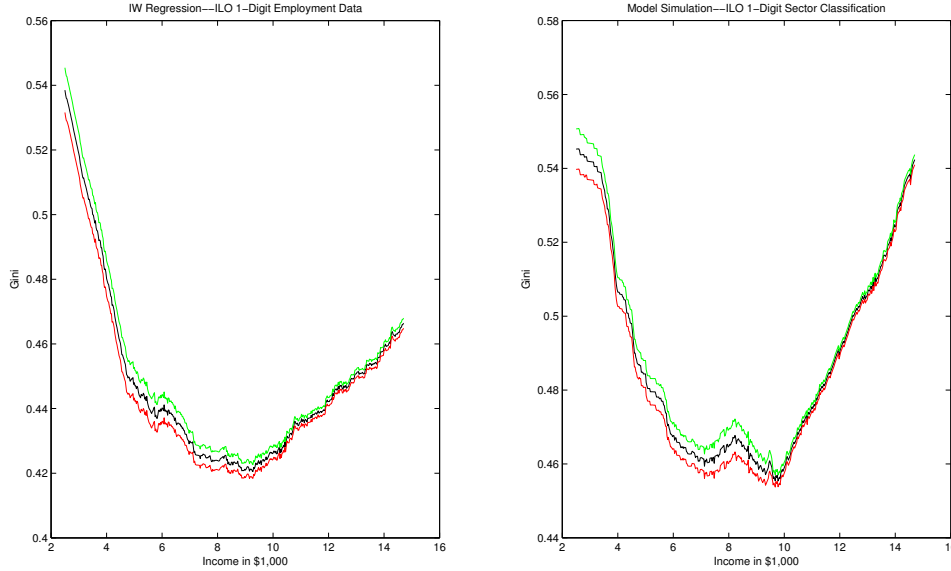


Figure 10. Economic Structure along the Development path: results for the entire economy, using the ILO 1-Digit Sector Classification. The left panel represents the ILO employment data, whereas the right panel is based on model-generated shares.

Within the manufacturing sector (for both capital and non-capital manufacturing industries), resources will shift towards high-TFP growth industries, as calibrated elasticities of

⁴³Again, an adjustment is required due to the focus on an EGP. See Appendix.

substitution are above one. However across *sectors*, because the elasticity of substitution across the consumption sectors is *less* than unity, the model predicts that the economy will shift resources towards the *slowest* TFP growth sector. During this process of structural change, the economy displays a U-shaped pattern of stages of diversification at both levels of disaggregation. This is exactly what we observe in the data in Figure 6 in the main text.

A lot of attention has been devoted to explaining changes in the share of agriculture and services along the development path – see Ngai and Pissarides (2004, 2007), Rogerson (2008) and Duarte and Restuccia (2010), among others. Although not designed to do so, the model matches extremely well the observed changes in the link between agricultural shares and service shares and income. See Figure 11.⁴⁴

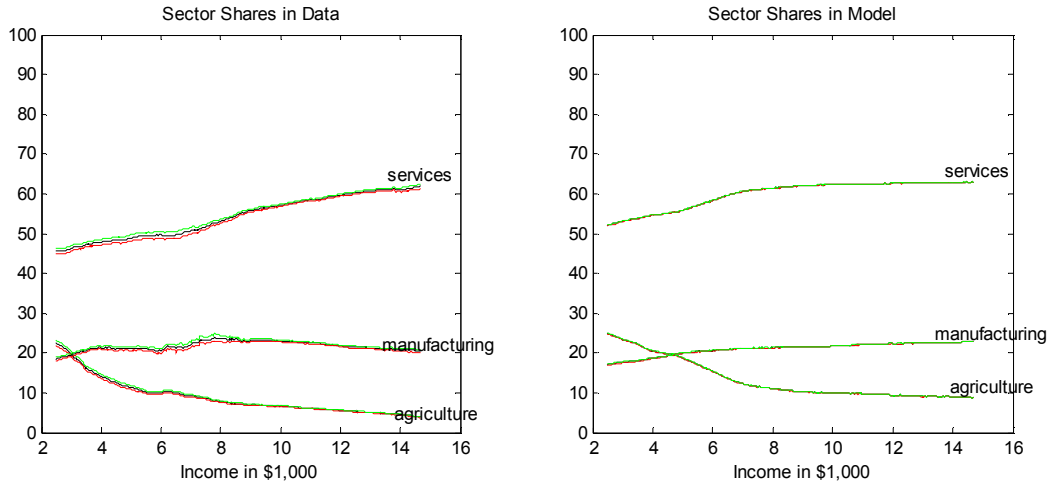


Figure 11. IW regressions for shares of agriculture, manufacturing and services. The left panel is based on the ILO data. The right panel is based on the model-generated shares.

D Simulation procedure

Simulating the model requires overcoming two distinct problems.

The first concerns matching the model with the data. Notice that the model reduces to a 2 sector model where consumption and investment are made by different sectors. As shown

⁴⁴The model does not produce a hump shape in the share manufacturing, which some authors have focused on (e.g. Buera and Kaboski (2012)). Pooling lots of countries and using the IW method, the data do seem to display a hump but it is weak compared to the dramatic rise of services and fall in agriculture, which the model does reproduce. Duarte and Restuccia (2010) show that a model with our basic mechanisms plus non-homothetic preferences can reproduce the hump.

in Greenwood, Hercowitz and Krusell (1997), this is the same as a one-sector model with investment specific technical change. In the one-sector growth model, the equilibrium for any initial conditions is a jump to the stable branch of a saddle path that leads to the long run equilibrium (which in this case is the model where the capital sector has converged to contain only one industry). Thus, for general initial conditions K_0 , the share of investment will jump after period 1, so that the structure of the manufacturing sector will change abruptly after period zero (and smoothly thereafter).

We handle this problem in two ways. First, we computed everything without worrying about the jump. Second, we calibrated the model so as to focus on an Euler growth path – which are the results reported in the paper (results were very similar either way).

In this second case we did not set the initial value of the capital stock K_0 to match the investment share of GDP in each country. The reason was that, in all other periods after $t = 0$, the investment share will follow the Euler equation. It seems arbitrary to assume that in all countries the Euler equation is satisfied in all years except 1963, or whatever happens to be the year for which data are initially available. As a result, we assume that the Euler equation is also satisfied at date zero. We call this an "Euler growth path" or EGP. To do this requires setting the investment share of GDP at a value that is different from that in the data. At the same time, it is critical that we preserve the composition of manufacturing. Hence, we adopted a recursive strategy. We know from the data the composition of investment in year zero. Given an assumption on the investment to GDP ratio, we can preserve the ratio of capital to manufacturing and find a value for the size of manufacturing that preserves its composition.⁴⁵ Then we check whether the assumption on the investment to GDP ratio corresponds to an EGP.⁴⁶ If not, then we generate another guess based on the predicted EGP value from the last iteration. We find that 3 loops is sufficient for very tight convergence. When we regress data on initial manufacturing shares on the model initial manufacturing shares, we find a coefficient of 1.16 (positive and close to one) and an intercept of -0.026 (close to zero), both significant at the 1% level. We take this to imply that, in general, our procedure does not significantly distort the sector structure of the model economy.

The second computational issue we confront is the fact that we are simulating a model

⁴⁵Other sectors are resized so that, relative to each other, shares of GDP are preserved too.

⁴⁶Recall that computing the equilibrium, including the initial share of investment, requires a series for g_c , which in turn depends on sector productivity growth rates. However, sector productivity growth rates depend on the initial composition and size of the economy. This is why an iterative procedure is necessary to find an EGP.

economy that does not have a balanced growth path (although it converges to one). Recall that the aggregate behavior of the model is the same as a one-sector model with investment specific technical change. In the one-sector growth model, any approximation to the saddle path will "shadow" it for a period of time, eventually diverging infinitely from it: see Colucci (2001). As a result, we adopt a procedure to provide this "shadowing" without suffering an eventual divergence.

The procedure is to assume limited computational ability among the agents, a procedure we call "rolling windows of consciousness." Specifically, the structure of the model economy can be computed exactly given the investment share of employment. This can be computed exactly given a series for g_{ct} , which is determined by Euler equation (55) and the transversality condition. The Euler equation converges uniformly to $g_{ct} = \bar{g}_{A_{St}}^{\frac{1}{1-\alpha}}$, where $\bar{g}_{A_{St}}$ is the weighted-average productivity in the manufacturing industry and which is known for any t given initial conditions and using equation (6). We assume that an agent at date t acts as though difference equation (55) characterizes g_{ct} up to period $t + T$, whereas after $t + T$ the agent believes that $g_{ct} = \bar{g}_{A_{St}}^{\frac{1}{1-\alpha}}$. Notice that this is distinct from simulating the transition path of the economy assuming that there is some fixed date T in the future after which productivity dynamics in the model economy change and correspond to a BGP:⁴⁷ we found that that procedure to be sensitive to the value of T . Instead, the horizon over which the agent uses the exact Euler equation (6) does not change over time.

We tried $T = 50, 90$ and 200 . For $T = 90$, the error between the realized value of g_{c1} and the value forecast by the agent when making investment and consumption decisions in period 0 is about 1% of the actual value (because the series for g_{ct} converges uniformly to its long run value, the forecast errors are the highest in the first period). For $T = 200$ these values are indistinguishable to eight decimal places. At the same time, for all values of T , the Gini nonparametric regression results such as Figure 4 were indistinguishable regardless of the value of T .

This indicates two results. First, this procedure could yield an arbitrarily accurate approximation to the correct aggregate equilibrium dynamics, given a sufficiently large (but finite) value of T . This is distinct from the shadowing property, which provides arbitrarily precise approximations only for a finite period, after which there is increasing divergence. Second, industry dynamics are robust even to using values of T such that aggregate dynamics are computed with some degree of imprecision.

⁴⁷See for example He and Liu (2008).

E Proofs

Proof of decentralized economy. For consumers:

$$\begin{aligned}
 & \max_{y_{st}} \sum_{t=0}^{\infty} \beta^t \frac{c_t^{1-\theta} - 1}{1-\theta} \\
 c_t &= \left[\sum_{s=1}^{S-1} \zeta_s y_{st}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} \\
 s.t. \quad & \sum_{s=1}^{S-1} q_{st} y_{st} + q_{St} y_{St} = \sum_{s=1}^S \sum_{i \in I_s} r_t K_{it} + \sum_{s=1}^S \sum_{i \in I_s} w_t n_{it}
 \end{aligned}$$

Capital and labor market clearing conditions are:

$$\begin{aligned}
 K_t &= \sum_{s=1}^S \sum_{i \in I_s} K_{it} \\
 1 &= \sum_{s=1}^S \sum_{i \in I_s} n_{it}
 \end{aligned}$$

F.O.C w.r.t y_{st} :

$$\frac{q_{st}}{q_{s't}} = \left(\frac{y_{s't}}{y_{st}} \right)^{\frac{1}{\varepsilon}} \frac{\zeta_s}{\zeta_{s'}} \quad s, s' = 1, \dots, S-1 \quad (33)$$

or

$$\frac{y_{st}}{y_{s't}} = \left(\frac{\zeta_s p_{s't}}{\zeta_{s'} p_{st}} \right)^{\varepsilon} \quad s, s' = 1, \dots, S-1 \quad (34)$$

Final Goods Sector s maximizes profit:

$$\begin{aligned}
 & \max_{u_{s,i,t}} q_{st} y_{st} - \sum_{i \in I} p_{it} u_{s,i,t} \\
 &= q_{st} \left[\sum_{i \in I} \xi_{s,i} \times y_{i,t}^{\frac{\varepsilon_s-1}{\varepsilon_s}} \right]^{\frac{\varepsilon_s}{\varepsilon_s-1}} - \sum_{i \in I} p_{it} y_{i,t}
 \end{aligned}$$

F.O.C w.r.t $y_{i,t}$:

$$q_{st} \left[\sum_{i \in I} \xi_{s,i} \times y_{i,t}^{\frac{\varepsilon_s-1}{\varepsilon_s}} \right] \xi_{s,i} y_{i,t}^{\frac{-1}{\varepsilon_s}} = p_{it}$$

similarly for $y_{j,t}$:

$$q_{st} \left[\sum_{i \in I} \xi_{s,i} \times y_{i,t}^{\frac{\varepsilon_s-1}{\varepsilon_s}} \right] \xi_{s,j} y_{j,t}^{\frac{-1}{\varepsilon_s}} = p_{jt}$$

So we have:

$$\frac{p_{it}}{p_{jt}} = \left(\frac{y_{j,t}}{y_{i,t}} \right)^{\frac{1}{\varepsilon_s}} \frac{\xi_{s,i}}{\xi_{s,j}} \quad (35)$$

or

$$\frac{y_{i,t}}{y_{j,t}} = \left(\frac{\xi_{s,i} p_{jt}}{\xi_{s,j} p_{it}} \right)^{\varepsilon_s} \quad (36)$$

For industry i in a given sector:

$$\max p_{it} A_{it} K_{it}^\alpha n_{it}^{1-\alpha} - r_t K_{it} - w_t n_{it}$$

F.O.C w.r.t K_{it} :

$$p_{it} \alpha A_{it} K_{it}^{\alpha-1} n_{it}^{1-\alpha} = r_t \quad (37)$$

F.O.C w.r.t n_{it} :

$$p_{it} (1 - \alpha) A_{it} K_{it}^\alpha n_{it}^{-\alpha} = w_t \quad (38)$$

Dividing one F.O.C. by the other we get that

$$\frac{1 - \alpha}{\alpha} \left(\frac{K_{it}}{n_{it}} \right) = \frac{w_t}{r_t} \Rightarrow k_t = \frac{w_t}{r_t} \times \frac{\alpha}{1 - \alpha} \quad (39)$$

where the capital labor ratio $k_t \equiv K_{it}/n_{it}$ is a constant across industries. Applying this result to (37) implies that

$$\frac{A_{it}}{A_{jt}} = \frac{p_{jt}}{p_{it}} \quad (40)$$

Using (36), (39) and (40) yields

$$\frac{n_{it}}{n_{jt}} = \left(\frac{\xi_{s,i}}{\xi_{s,j}} \right)^{\varepsilon_s} \left(\frac{A_{it}}{A_{jt}} \right)^{\varepsilon_s - 1} \quad (41)$$

which, rearranging (35), implies that $\frac{n_{it}}{n_{jt}} = \frac{p_{it} y_{it}}{p_{jt} y_{jt}}$. Define the industry i growth factor as :

$$G_{it} = \frac{p_{i,t+1} y_{i,t+1}}{p_{it} y_{it}}$$

and the expression G_{it}/G_{jt} then denotes the growth of industry i relative to industry j

$$\begin{aligned} \frac{G_{it}}{G_{jt}} &= \frac{\frac{p_{i,t+1} y_{i,t+1}}{p_{it} y_{it}}}{\frac{p_{j,t+1} y_{j,t+1}}{p_{jt} y_{jt}}} = \frac{\frac{p_{i,t+1}}{p_{j,t+1}} \left(\frac{\xi_{s,i} p_{j,t+1}}{\xi_{s,j} p_{i,t+1}} \right)^{\varepsilon_s}}{\frac{p_{it}}{p_{jt}} \left(\frac{\xi_{s,i} p_{jt}}{\xi_{s,j} p_{it}} \right)^{\varepsilon_s}} \\ &= \frac{\left(\frac{p_{i,t+1}}{p_{j,t+1}} \right)^{1-\varepsilon_s}}{\left(\frac{p_{it}}{p_{jt}} \right)^{1-\varepsilon_s}} = \frac{\left(\frac{A_{i,t+1}}{A_{it}} \right)^{\varepsilon_s - 1}}{\left(\frac{A_{j,t+1}}{A_{jt}} \right)^{\varepsilon_s - 1}} \\ &= \left(\frac{g_i}{g_j} \right)^{\varepsilon_s - 1} \end{aligned}$$

■

Proof of Proposition 1. Solving the 2 sector problem and using the equilibrium conditions, we have:

$$A_{St} = p_{ct} A_{ct} \quad (42)$$

$$r_t = \frac{\frac{p_{ct} c_t^\theta}{p_{ct-1} c_{t-1}^\theta}}{\beta} - 1 + \delta = \frac{\left(\frac{\bar{g}_{A_{S,t-1}}}{\bar{g}_{A_{c,t-1}}}\right)^{1-\theta} g_{ct-1}^\theta}{\beta} - 1 + \delta \text{ IF } \beta \neq 0 \quad (43)$$

$$\text{where } g_{ct-1} \equiv \frac{p_t c_t}{p_{t-1} c_{t-1}} \text{ is the growth factor of aggregate consumption} \quad (44)$$

$$\bar{g}_{A_{ct-1}} = \frac{A_{ct}}{A_{c,t-1}}, \bar{g}_{A_{S,t-1}} = \frac{A_{St}}{A_{S,t-1}} \text{ are known} \quad (45)$$

Let $\phi_t = \alpha^{-1} r_t^{\frac{-\alpha}{1-\alpha}} - \bar{g}_{A_{S,t}}^{\frac{1}{1-\alpha}} r_{t+1}^{\frac{-1}{1-\alpha}} + (1-\delta) r_t^{\frac{-1}{1-\alpha}}$

$$\begin{aligned} k_t &= \frac{K_{St}}{n_{St}} = \frac{K_{ct}}{n_{ct}} = \left(\frac{\alpha A_{St}}{r_t} \right)^{\frac{1}{1-\alpha}} \\ K_t &= k_t \end{aligned}$$

The growth factor of capital per capita in each sector is:

$$g_{k_t} = \frac{k_{t+1}}{k_t} = \bar{g}_{A_{St}}^{\frac{1}{1-\alpha}} \left(\frac{r_t}{r_{t+1}} \right)^{\frac{1}{1-\alpha}} \quad (46)$$

Similarly, we get aggregate capital growth factor:

$$g_{K_t} = g_{k_t}$$

Using (42) and (26), we derive capital sector output, i.e., investment:

$$\begin{aligned} y_{St} &= \left(\frac{\alpha A_{St+1}}{r_{t+1}} \right)^{\frac{1}{1-\alpha}} - (1-\delta) \left(\frac{\alpha A_{St}}{r_t} \right)^{\frac{1}{1-\alpha}} \\ &= (\alpha A_{St})^{\frac{1}{1-\alpha}} \left[\left(\frac{\bar{g}_{A_{S,t}}}{r_{t+1}} \right)^{\frac{1}{1-\alpha}} - (1-\delta) \left(\frac{1}{r_t} \right)^{\frac{1}{1-\alpha}} \right] \end{aligned} \quad (47)$$

and the growth factor of investment y_{St} is:

$$g_{y_{St}} = \frac{y_{S,t+1}}{y_{St}} = \bar{g}_{A_{St}}^{\frac{1}{1-\alpha}} \frac{\left(\frac{\bar{g}_{A_{S,t+1}}}{r_{t+2}} \right)^{\frac{1}{1-\alpha}} - (1-\delta) \left(\frac{1}{r_{t+1}} \right)^{\frac{1}{1-\alpha}}}{\left(\frac{\bar{g}_{A_{St}}}{r_{t+1}} \right)^{\frac{1}{1-\alpha}} - (1-\delta) \left(\frac{1}{r_t} \right)^{\frac{1}{1-\alpha}}}$$

so that the labor in capital sector is:

$$n_{S,t} = \alpha \left[\frac{1}{r_t} \left(\frac{\bar{g}_{A_{S,t}} r_t}{r_{t+1}} \right)^{\frac{1}{1-\alpha}} - \frac{(1-\delta)}{r_t} \right] \quad (48)$$

and the growth factor of n_{ht} is:

$$g_{n_{St}} = \frac{n_{S,t+1}}{n_{St}} = \frac{\frac{1}{r_{t+1}} \left(\frac{\bar{g}_{AS,t+1} r_{t+1}}{r_{t+2}} \right)^{\frac{1}{1-\alpha}} - \frac{(1-\delta)}{r_{t+1}}}{\frac{1}{r_t} \left(\frac{\bar{g}_{AS,t} r_t}{r_{t+1}} \right)^{\frac{1}{1-\alpha}} - \frac{(1-\delta)}{r_t}} \quad (49)$$

Notice that n_{St} (and hence $n_{ct} = 1 - n_{St}$) is independent of the level of technology in c and y_S as long as the interest rate is too. We can get capital in capital sector:

$$K_{S,t} = \alpha \left[\frac{1}{r_t} \left(\frac{\bar{g}_{AS,t} r_t}{r_{t+1}} \right)^{\frac{1}{1-\alpha}} - \frac{(1-\delta)}{r_{t+1}} \right] \left(\frac{\alpha A_{St}}{r_t} \right)^{\frac{1}{1-\alpha}} \quad (50)$$

Define the aggregate output per capita as $y_t = y_{St} + p_{ct} c_{ct}$. Since $K_{ct} = K_t - K_{St}$ and $n_{ct} = 1 - n_{St}$,

$$\begin{aligned} y_t &= y_{St} + p_{ct} c_{ct} \\ &= A_{St} K_{St}^\alpha n_{St}^{1-\alpha} + p_{ct} A_{ct} K_{ct}^\alpha n_{ct}^{1-\alpha} \\ &= A_{St} k_t^{\frac{\alpha}{1-\alpha}} = \left(\frac{\alpha}{r_t} \right)^{\frac{\alpha}{1-\alpha}} A_{St}^{\frac{1}{1-\alpha}} \end{aligned} \quad (51)$$

and its growth factor is:

$$g_{yt} = \frac{y_{t+1}}{y_t} = \bar{g}_{AS,t} \left(\frac{r_t}{r_{t+1}} \right)^{\frac{\alpha}{1-\alpha}} \quad (52)$$

Aggregate consumption is:

$$\begin{aligned} C_t &= p_{ct} c_{ct} = y_t - y_{St} \\ &= \left(\frac{\alpha}{r_t} \right)^{\frac{\alpha}{1-\alpha}} A_{St}^{\frac{1}{1-\alpha}} \end{aligned} \quad (53)$$

$$- (\alpha A_{St})^{\frac{1}{1-\alpha}} \left[\left(\frac{\bar{g}_{AS,t}}{r_{t+1}} \right)^{\frac{1}{1-\alpha}} - (1-\delta) \left(\frac{1}{r_t} \right)^{\frac{1}{1-\alpha}} \right] \quad (54)$$

The growth factor of consumption is:

$$g_{ct} = \frac{C_{t+1}}{C_t} = \bar{g}_{AS,t} \frac{\phi_{t+1}}{\phi_t}. \quad (55)$$

Notice that as $t \rightarrow \infty$ the expressions for $\bar{g}_{AS,t}$ and $\bar{g}_{AC,t}$ converge to constants, so the difference equation for g_{ct} converges uniformly to that which characterizes the model of investment-specific technical change in Greenwood, Hercowitz and Krusell (1997). Thus, the result that the transversality condition picks out a single equilibrium solution in that model extends to our case too. ■

Proof of Proposition 2. Corollary of the proof of Proposition 1 and (17). ■

F Measurement of productivity in Manufacturing

We measure productivity using the NBER Manufacturing Productivity Database. The data are more disaggregated than the ISIC3 Classification we need for the UNIDO data, so we aggregate them using Domar weights.

In addition, we use an alternative way of measuring TFP growth rates. Using the UNIDO dataset, we compute the TFP growth rates of 28 UNIDO manufacturing industries of the United States using the following equation:

$$\ln(TFP_{it}) = \ln(Y_{it}) - (1 - \alpha) \ln(L_{it}) - \alpha \ln(K_{it}) \quad (56)$$

where Y_{it} is the production index. This requires computing the capital stock at the industry level. The UNIDO dataset provides investment data but not capital stock data K_{it} , so we use a perpetual inventory method

$$K_{it+1} = (1 - \delta)K_{it} + I_{it}q_{it} \quad (57)$$

to compute growth rate of capital stock, where I_{it} is investment and q_{it} represents investment-specific technical progress⁴⁸. Then the growth rate of K_{it} is the sum of growth rates of I and q . We set $q_{it} = g_{iq}^t$, so that growth rates of q_i vary across industries. We use growth factor g_{iq} from IS. Also, $\delta = 0.06$ and $\alpha = 0.3$. These are standard numbers in the literature.⁴⁹ Then, if $\Gamma(x)$ is the log growth rate of x over the time period in the data, note that

$$\ln g_i = \Gamma(Y_i) - (1 - \alpha)\Gamma(L_i) - \alpha\Gamma(K_i) \quad (58)$$

We obtain $\Gamma(Y_i)$ and $\Gamma(L_i)$ from UNIDO, and set $\Gamma(K_i) = \Gamma(L_i) + \log g_{iq}$, which is the long run relationship in (57). See Table 6.

⁴⁸We need to allow for investment-specific technical progress because the model is one with many industries where productivity growth rates in capital-producing industries may be different from productivity growth elsewhere.

⁴⁹The value of δ is from Greenwood, Hercowitz and Krusell (1997) and is a value typical in models with investment-specific technical change, in other words where $g_q > 1$.

G Intermediate goods

We have abstracted from the existence of intermediate goods. There is a question as to whether results might change if we allowed for intermediates. For one thing, when there are intermediate goods, Ngai and Samaniego (2009) point out that TFP growth measures computed using gross output data (as is the case for the NBER numbers) understate TFP growth in a value added model.

Consider that the input-output matrix is largely diagonal: industries tend to use intermediates produced within the industry. Let us abstract from the off-diagonal elements. In this case, the production function is

$$y_{it} = A_{it} (K_{it}^\alpha n_{it}^{1-\alpha})^{1-\psi} x_{it}^\psi \quad (59)$$

where x_{it} are intermediate goods and ψ is the intermediate goods share. Producers solve the problem

$$\max_{k_{it}, n_{it}, x_{it}} \{p_{it}y_{it} - w_t n_{it} - r_t K_{it} - p_{it}x_{it}\}. \quad (60)$$

Solving for optimal use of x_{it} , It is easy to show that this is equivalent to solving

$$\max_{k_{it}, n_{it}} \{p_{it}\tilde{y}_{it} - w_t n_{it} - r_t K_{it}\}. \quad (61)$$

where $\tilde{y}_{it} = y_{it} - x_{it}$ is value added in terms of good i , with the value-added production function

$$\begin{aligned} \tilde{y}_{it} &= p_{it} \tilde{A}_{it} K_{it}^\alpha n_{it}^{1-\alpha} \\ \tilde{A}_{it} &= A_{it}^{\frac{1}{1-\psi}} \left[\psi^{\frac{\psi}{1-\psi}} - \psi^{\frac{1}{1-\psi}} \right]. \end{aligned} \quad (62)$$

While (62) is of the same form as (13), note that the growth factor of $\tilde{A}_{it}$ is equal to $g_i^{\frac{1}{1-\psi}} > g_i$.

At the same time, this does not matter for the results. Recall that what affects rates of structural change in the model is the combination of g_i and ε , not one or the other in isolation. If we regress the log value added growth on the log real value-added productivity factor $g_i^{\frac{1}{1-\psi}}$, we would obtain a different value of epsilon. Recall that (6) is equivalent to $\log G_i = \alpha + (\varepsilon - 1) \log g_i + \epsilon_i$ where $\alpha = \log G_j - \log g_j$ for some arbitrary industry j and ϵ_i is any unmodeled noise. If we use g_i instead of $g_i^{\frac{1}{1-\psi}}$ in this equation, we would have an estimated elasticity $\tilde{\varepsilon}$ where $\tilde{\varepsilon} - 1 = (\varepsilon - 1)(1 - \psi)$ – a lower value, since $\psi < 1$. However, structural change within sectors would be driven by the following relationship

$$\frac{G_{it}}{G_{jt}} = \left[\frac{g_i^{\frac{1}{1-\psi}}}{g_j^{\frac{1}{1-\psi}}} \right]^{\tilde{\varepsilon}-1} = \left[\frac{g_i}{g_j} \right]^{\frac{\tilde{\varepsilon}-1}{1-\psi}} = \left[\frac{g_i}{g_j} \right]^{\varepsilon-1}, \quad (63)$$

which is exactly equivalent quantitatively to patterns of structural change in our model without intermediates. Thus, significant off-diagonal elements in the input-output tables would be required to change our quantitative results.

A similar intuition regards the possibility of adjustment costs in the reallocation of capital cross industries. Given other parameters, capital adjustment costs could slow the reallocation of resources across industries. However in the presence of adjustment costs the value of ε required to match the link between industry growth and TFP growth in the data would be larger. Thus, results would not be affected.

H Industry TFP growth data

I Convergence dynamics with the alternate TFP measures

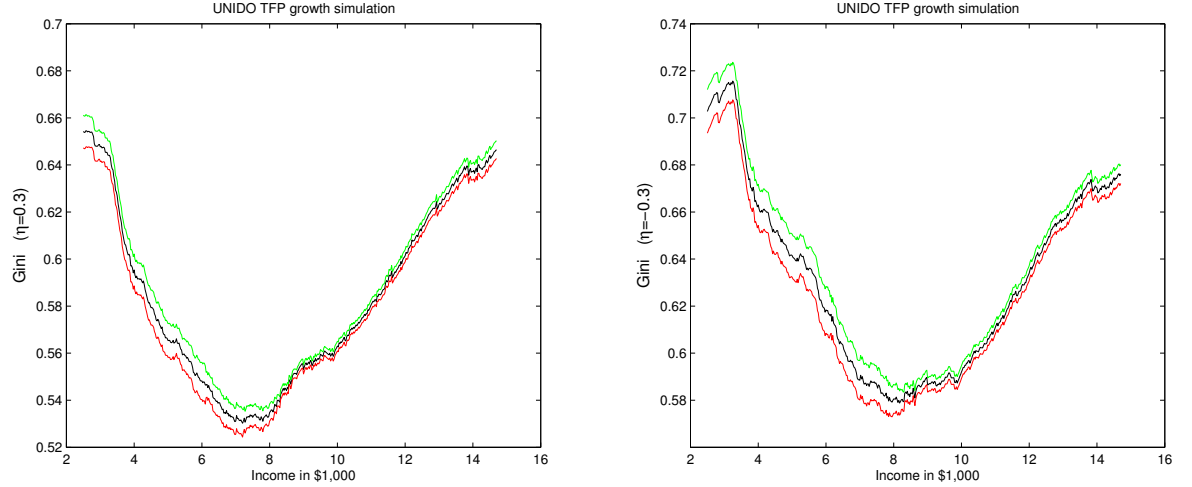


Figure 12 - Industry structure along the development path allowing for convergence in TFP growth rate across countries using UNIDO TFP. Productivity growth g_{ict} equals $g_{ct}g_i^{x_{c,t}^\eta}$ where the output gap $x_{c,t}$ is defined as $Y_{c,t}/Y_{US,t}$.

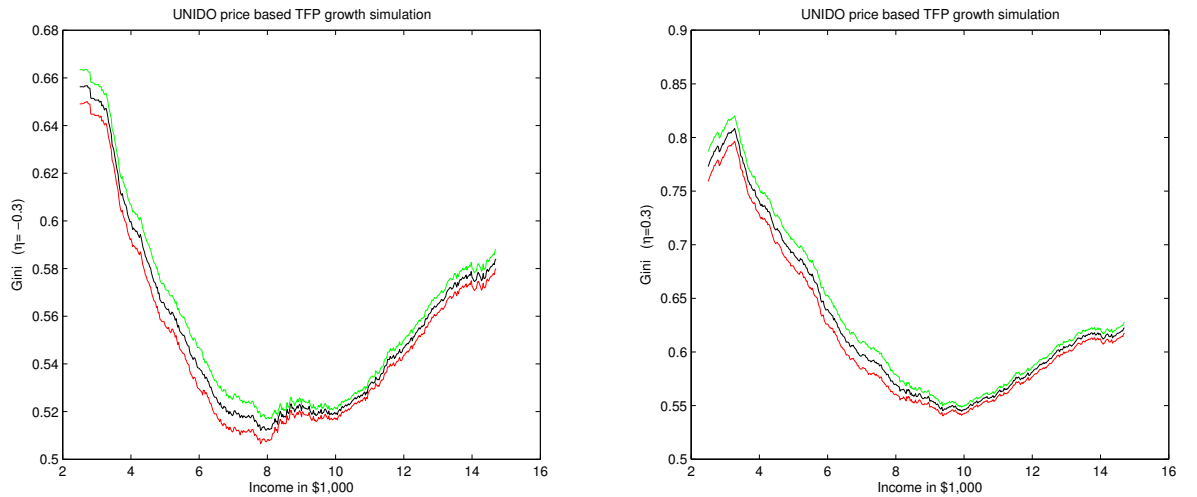


Figure 13 - Industry structure along the development path allowing for convergence in TFP growth rate across countries using UNIDO price. Productivity growth g_{ict} equals $g_{ct}g_i^{x_{c,t}^\eta}$ where the output gap $x_{c,t}$ is defined as $Y_{c,t}/Y_{US,t}$.

Table 4: NBER TFP Growth Rates for the ISIC revision 2 industry classification. Source: NBER productivity database and authors' calculations.

Industry	ISIC code	NBER TFP Growth Rate
Food products	311	0.0101
Beverages	313	0.0303
Tobacco	314	-0.0345
Textiles	321	0.0269
Apparel	322	0.0121
Leather	323	-0.0034
Footwear	324	-0.0035
Wood products	331	0.0113
Furniture, except metal	332	0.0066
Paper and products	341	0.0088
Printing and publishing	342	-0.0022
Industrial chemicals	351	0.0214
Other chemicals	352	0.0135
Petroleum refineries	353	0.0196
Misc. pet. and coal products	354	0.0223
Rubber products	355	0.0142
Plastic products	356	0.0339
Pottery, china, earthenware	361	0.0078
Glass and products	362	0.0051
Other non-metallic mineral prod.	369	0.0120
Iron and steel	371	0.0047
Non-ferrous metals	372	0.0016
Fabricated metal products	381	0.0029
Machinery, except electrical	382	0.0285
Machinery, electric	383	0.0347
Transport equipment	384	0.0160
Prof. & sci. equip.	385	0.0126
Other manufactured prod.	390	0.0089

Table 5: Productivity growth across broad ILO Sectors. The manufacturing sector is composed of the 28 ISIC2 industries. The value for Manufacturing in the table is the average over the sample period in the NBER data.

ILO 1-Digit Classification (9 sectors)		Growth Factor g
1	Agriculture, Hunting, Forestry and Fishing	1.027
2	Mining and Quarrying	0.995
3	Manufacturing*	1.012
4	Electricity, Gas and Water	0.987
5	Construction	0.983
6	Wholesale and Retail Trade and Restaurants and Hotels	1.011
7	Transport, Storage and Communication	1.006
8	Financing, Insurance, Real Estate and Business Services	0.982
9	Community, Social and Personal Services	0.974

Table 6: UNIDO TFP and Price Growth Rate

Industry	ISIC code	UNIDO TFP Growth Rate	UNIDO Price Growth Rate
Food products	311	0.0067	0.0424
Beverages	313	0.0244	0.0295
Tobacco	314	-0.0212	0.0941
Textiles	321	0.0090	0.0328
Apparel	322	0.0060	0.0371
Leather	323	-0.0196	0.0570
Footwear	324	0.0034	0.0438
Wood products	331	-0.0014	0.0464
Furniture, except metal	332	0.0064	0.0352
Paper and products	341	0.0019	0.0410
Printing and publishing	342	-0.0062	0.0499
Industrial chemicals	351	0.0225	0.0201
Other chemicals	352	0.0146	0.0322
Petroleum refineries	353	-0.0089	0.0507
Misc. pet. and coal products	354	-0.0168	0.0552
Rubber products	355	0.0287	0.0172
Plastic products	356	0.0321	0.0132
Pottery, china, earthenware	361	-0.0116	0.0428
Glass and products	362	0.0005	0.0358
Other non-metallic mineral prod.	369	0.0040	0.0375
Iron and steel	371	-0.0006	0.0377
Non-ferrous metals	372	-0.0103	0.0472
Fabricated metal products	381	0.0034	0.0392
Machinery, except electrical	382	0.0330	0.0025
Machinery, electric	383	0.0218	0.0167
Transport equipment	384	-0.0118	0.0488
Prof. & sci. equip.	385	-0.0027	0.0425
Other manufactured prod.	390	0.0170	0.0290