

Accounting for Structural Change Over Time: A Case Study of Three Middle-Income Countries*

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Abstract

We review the main mechanisms of structural change: non-homothetic preferences, asymmetric productivity growth couple with non-unitary elasticities of substitution and comparative advantage and international trade, as well as several additional mechanisms. We then present some key established and recent facts of structural change. To understand these facts better, we develop a dynamic, multi-sector, multi-country model of structural change that embodies the mechanisms we review. We calibrate the model, and back out the “wedges” that account for the evolution of the model’s endogenous variables. Then, focusing on the evolution of the industry employment share in Hungary, Portugal, and South Korea post-1990, we conduct several structural accounting decompositions. Our decompositions suggests that several of the mechanisms play important roles in the evolution of the industry employment share and of openness in these countries.

JEL Classifications: F11, F43, O41, O11

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1 Introduction

Since at least the time of Kuznets’ path breaking research, economists have sought to document and explain the phenomena that accompany countries’ growth and development – their structural change. Structural change encompasses many dimensions, but the dimension that is most commonly focused on involves the reallocation of factors of production between sectors so that value-added shares change across sectors as countries grow over time. The most well known fact about such reallocation is the shift in factors of production, and value-added, away from agriculture to industry and services. The shift to industry is not long-lasting, however, as most countries experience a “hump” pattern in industry employment or value-added as shares of total employment or value-added, respectively.

In recent years, as more countries have accumulated longer durations of structural change, some new facts have emerged. For instance, the “peak” of the hump of industry employment share has been lower than in the past.¹ In other words, the “peak” of the hump in industry has been lower than in the past. This, and related facts, are interesting, because they suggest that structural change itself is changing.

Because structural change is closely associated with a country’s growth, structural change can help shed light on the growth process, and vice versa. Are there unique features about structural change that are associated with “growth miracle” countries compared to countries stuck in “middle income traps”? Do the countries stuck in middle income traps need to undergo more rapid structural change? These questions are so important that they demand a broad and deep research agenda.

In this paper, our goal is to begin to address these questions by developing a multi-sector, multi-country open economy framework for structural change that encompasses seven mechanisms. We then calibrate the model, and back out the exogenous variables and time-varying parameters that fully explain, or account for, the data. The exogenous variables and time-varying parameters embody the seven mechanisms. Finally, we conduct counterfactual simulations with the wedges to try to understand different countries’ patterns of structural change.

Among the seven mechanisms in our model are three of the most important mechanisms previously employed by models of structural change. The first mechanism is non-homothetic preferences, which implies that the income elasticity of demand deviates from one in more than one sector. Income growth, particularly in the sectors with the non-unitary income

¹We define industry as manufacturing+mining+utilities+construction.

elasticity, will then drive shifts in sectoral demand with consequent effects on sectoral employment and value-added. The second mechanism is asymmetric sectoral productivity growth coupled with non-unitary substitution elasticities. If the substitution elasticities are less than one, for example, then sectors with high productivity growth will experience relative price-induced decreases in demand with consequent effects on sectoral employment and value-added. The third mechanism is comparative advantage and international trade. As countries open up to international trade, they specialize in the sectors of their comparative advantage, which can have strong implications for the allocation of employment and production across sectors.

In addition, our framework includes four additional mechanisms: intermediate goods and input-output linkages; labor “wedges”; investment rates; and trade imbalances. Each mechanism is motivated by key features of the data. For example, the importance of intermediate goods and the nature of sectoral input-output linkages both evolve as countries become richer. These changes alter the link between the sectoral composition of demand and the sectoral composition of supply. In addition, it is well known that labor is not fully mobile across sectors. The labor wedges in our model imply that the marginal product of labor need not equalize across sectors affecting the allocation of employment. Because investment is comprised primarily of industrial goods (manufacturing and construction, specifically), changes in the aggregate investment rate induce changes in the demand for industrial production. Aggregate trade imbalances allow for the possibility of changes in net exports in one sector, without an offsetting change in net exports in another sector, thereby providing the model the needed flexibility to speak to both the sectoral and the aggregate trade data. All together, our framework includes seven mechanisms.

We calibrate the key parameters of the model, and we include 28 countries plus a composite rest-of-the-world covering 1970 to 2011. We then use the calibrated model to solve for the exogenous variables and time varying parameters corresponding to each of the mechanisms above that enable the model to fit the sectoral trade, GDP, employment, expenditure, and other data as closely as possible. We call the exogenous variables and time-varying parameters collectively “wedges”. We then conduct a structural accounting decomposition by feeding subsets of the wedges back into the model, which yields implications for structural change.

Our approach generates on the order of a 100,000 wedges and there are many sets of structural accounting decompositions that could be done. Some narrowing of focus is needed. We focus on three countries, Hungary, Portugal, and South Korea. All three countries fit the

EBRD’s middle-income country concept as they are currently between one-third and two-thirds of U.S. per capita PPP GDP. South Korea is a middle-income success story that has essentially “graduated” to advanced income status with a PPP per capita GDP right around two-thirds of that of the United States. Hungary is the only East European economy that has long data series to unveil its transitional path from a command economy to a market system. Portugal is the country in Western or Southern Europe that is probably the closest to Hungary in overall per capita income. The two countries have had similar PPP per-capita income since 1970.

The wedges we back out from our model show that with a few exceptions, Hungary’s wedges and Portugal’s wedges tend to move in parallel or converge after 1990. For example, Hungary’s labor wedge (a measure of the frictions associated with the reallocation of labor across sectors) in services increased after 1990 and converged roughly to the level in Portugal. However, one exception is Hungary’s consumer preferences for industrial goods. This declined sharply after 1990. By contrast, South Korea’s wedges follow patterns different from those of Hungary and Portugal. For example, South Korea’s fundamental services productivity is relatively constant, while that of Hungary and Portugal are declining. South Korea’s fundamental manufacturing productivity increased rapidly since 1970, while that of Hungary and Portugal was either constant or declining.

For our structural accounting decomposition, we ask: “If a particular country’s wedge is held constant at its 1970 value, instead of evolving as it did, and if all other wedges evolve as they actually did in the data, what would be the implications for the industry share of employment?” We focus on understanding the industry employment share, and also the surge in Hungary’s openness in industry following 1990. Comparing Hungary and South Korea, for each of productivity and trade barriers, holding the wedge constant leads to the same qualitative behavior of the industry employment share. On the other hand, Hungary’s sharp decline in preferences for industry goods implies that the counterfactual of holding preferences constant at their 1970 value will yield an employment share in industry several percentage points higher than in the baseline. In Korea, the opposite occurs.

We also use the decompositions, to address two particular patterns in Hungary. In 2000, Hungary’s and Portugal’s industry share of employment were quite similar at about 36 percent. In the ensuing decade, Hungary’s share stayed constant while Portugal’s fell by about seven percentage points. Our counterfactual analysis shows that evolving production structures over time can account for about two-thirds of this difference. In particular, the importance of industry as an intermediate in production became greater in Hungary, while

its importance slightly lessened in Portugal during the same period.

Second, Hungary had a surge in its trade-to-value-added ratio in industry following 1990 to the point where it was about double South Korea's. To understand this surge, we conduct counterfactuals in which Hungary's import barriers are held constant at their 1970 level, then the barriers to its exports are held constant at their 1970 level, and finally both sets of barriers are held constant at their 1970 level. Our exercise shows that declining export barriers accounted for more than two-thirds of the increase in Hungary's industry openness.

Our paper is most closely related to Świecki (2014). He also employs a wedge accounting exercise using a multi-country model of structural change. Relative to his paper, our model includes investment, input-output linkages, and trade imbalances. Furthermore, we focus our attention to a specific subset of middle-income countries to better understand the dynamics of industrial employment around the peak of the employment share. In addition, it is related to other multi-sector, multi-country models that have been employed to investigate, for example, the effects of NAFTA, the evolution of comparative advantage over time, and the changing nature of structural change – Caliendo and Parro (2015), Levchenko and Zhang (2016), and Sposi (2016).

The paper is organized as follows. Section 2 discusses the mechanisms underlying structural change in more detail. Section 3 presents the established and new stylized facts about structural change. Section 4 lays out our model. Section 5 describes how we calibrate the parameters of our model, and also solves for the wedges. The next section includes results from our structural accounting decomposition. Section 7 concludes.

2 Overview of broad mechanisms of structural change

In this section, we review the major theories and mechanisms of structural change. These theories are centered around four primary mechanisms, and we discuss the theories in terms of these mechanisms. The first, and oldest mechanism, captures Engel's Law – as countries get richer their preferences shift away from agriculture-related products towards manufacturing and services. In other words, the income elasticity of demand for broad categories of goods is not one – preferences are non-homothetic. The second mechanism is attributed to Baumol (1967), and involves the fact that goods are imperfect substitutes in consumption. This mechanism implies that asymmetric sectoral productivity growth induces structural change. For example, if the elasticities of substitution are all less than one, then the sector that has the highest productivity growth will experience a declining relative price and will

shrink over time – its employment and value-added shares will fall. Hence, the first two mechanisms depend heavily on non-unitary elasticities of income and substitution, respectively, with these elasticities originating typically from preferences. The third mechanism involves international trade – in particular, the forces of comparative advantage and specialization. The above are the most well-known mechanisms. We also present four additional mechanisms corresponding to the mechanisms in the model framework we develop in section 4: intermediate goods and input-output relations that connect sectors and countries; labor “wedges”; investment rates; trade imbalances.

In order to elucidate the mechanisms most clearly, we will narrow our discussion along the following lines. We will discuss each of these mechanisms in terms of their effects on sectoral employment shares of total employment and sector value-added shares of total value-added. In addition, we will discuss these mechanisms from the perspective of a three sector framework – agriculture, manufacturing/industry, and services – rather than a two sector framework (agriculture and non-agriculture), primarily because the behavior of manufacturing/industry is considerably different from that of services. When we discuss international trade, what we have in mind is comparative advantage based models of trade, and to be more specific, those models based on Ricardian comparative advantage. Finally, for simplicity, the first three mechanisms will be discussed from the perspective of a framework without intermediate goods.

2.1 Engel’s Law / non-homothetic preferences

Models of structural change capture the “Engel’s Law” mechanism by making preferences defined over the sectoral goods non-homothetic. In particular, to be consistent with Engel’s Law, the non-homotheticity involves an income elasticity of demand for agriculture-related products that is less than one; consequently, the income elasticity of demand for the two other sectors, taken together, is greater than one. The most common example of such preferences is Stone-Geary preferences:

$$U(C^a, C^m, C^s) = (C^a - \bar{C}^a)^{\omega_a} (C^m)^{\omega_m} (C^s)^{\omega_s}, \quad (1)$$

where C^k is consumption in sector k , and $\bar{C}^a > 0$ represents the subsistence level of consumption of agriculture-related goods. As a country’s per-capita income increases, its demand for agriculture-related goods increases less than proportionately, while its demand for manufactured goods and services together will increase more than one-for-one. In turn, this shift

in demand away from agriculture-related goods will lead to a smaller share of employment or value-added devoted to agriculture, and a larger share devoted to manufacturing and services. Because one of the dominant facts of structural change, as we will see in the next section, is the decline in agriculture as countries develop, this mechanism is usually present in all models of structural change. That said, one flaw with Stone-Geary preferences is that as a country continues to get richer, in the limit, the subsistence level of consumption becomes irrelevant and the income elasticity of demand for agriculture-related goods approaches one. This has led to the development of more sophisticated ways of modeling non-homotheticities, as we will discuss further below.

2.2 Baumol / Asymmetric sectoral productivity growth

The “Baumol” mechanism involves the interaction of non-unitary substitution elasticities in preferences across sectoral goods with asymmetric sectoral productivity growth. So, this mechanism involves both preferences and production. An example of such preferences is CES preferences in which the elasticity of substitution $\sigma \neq 1$:

$$U(C^a, C^m, C^s) = \left[\omega_a(C^a)^{\frac{\sigma-1}{\sigma}} + \omega_m(C^m)^{\frac{\sigma-1}{\sigma}} + \omega_s(C^s)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \quad (2)$$

Indeed, with $\sigma = 1$ this boils down to log utility. Now, consider a world in which the elasticity of substitution $\sigma < 1$ so that goods are gross complements. Further suppose that total factor productivity (TFP) growth is highest in manufacturing and lowest in services, with agriculture in between. In this world, the relative price of manufactured goods declines and the relative price of services rises. These changes in relative prices, in conjunction with the low elasticity of substitution, implies that total desired expenditure on manufactured goods will decline and total desired expenditure on services will increase. In turn, the changes in desired expenditure will lead to changes in employment and value-added. Hence, the employment share of manufacturing will decline, and the employment share of services will increase. The employment share of agriculture will be ambiguous.²

2.3 International trade

International trade affects structural change in at least four ways. The first is a direct consequence of forces leading to an increase or decrease in international trade. The second, third

²See Ngai and Pissarides (2007) for a presentation of this framework in a balanced growth context.

and fourth channels involve the interaction of international trade with the two mechanisms discussed above.

Suppose the costs of international trade decline. This will encourage specialization according to comparative advantage. If a country has a comparative advantage in manufacturing, for example, the lower costs of international trade will lead to increased demand for the country's manufactured goods. This increases employment and value-added in the manufacturing sector. In addition, the sectors that do not have a comparative advantage will experience decreases in employment and value-added. The reallocation of employment and value-added across sectors owing to changing specialization patterns induced by changing trade costs is the first channel.

The second channel involves a consequence of increased international trade. Real income will increase, which, in the presence of non-homothetic preferences, will induce a shift in the share of demand away from low income elasticity goods towards high income elasticity goods. This shift in desired expenditure will lead to changes in sectoral employment and value-added shares. Hence, the presence of trade can enhance the non-homothetic preference channel.

The third channel depends on the response of relative prices within a country and the complementarity in preferences, i.e., the second mechanism from above. Global declines in trade barriers can occur at different rates across sectors – faster declines in industry than in services, for instance. Such a pattern would result in declining prices of goods relative to services, and result in greater expenditure share on services, ultimately inducing higher higher employment shares in the service sector.

Finally, the fourth channel involves asymmetric sectoral productivity growth across countries affecting comparative advantage through the Ricardian mechanism. As the sectoral productivity differentials between countries change over time, countries face differing opportunity costs of production and results in different patterns of specialization.

To summarize, international trade exerts a direct effect on structural change, and it can enhance the non-homothetic preferences and asymmetric sectoral productivity growth mechanisms, as well.³

2.4 Four additional mechanisms

We now discuss each of the four additional mechanisms.

³See Uy, Yi, and Zhang (2013) for a more detailed discussion of the role of international trade in structural change.

2.4.1 Intermediate goods and input-output relations

*** Intermediate goods and input-output channels provide a mapping from changes in final demand into changes in value-added and employment. In our discussion above, for simplicity, we assumed a framework in which all production consists of value-added. In the absence of intermediate goods, there would be a direct, proportional, link from final demand to value-added and employment in the global economy or in a closed economy. In the data, however, the share of intermediate goods in production and international trade is high and is growing in many sectors. An example of a production function with intermediate goods and input-output linkages for sector k output in country i is the following:

$$Y^k = ((K^k)^\alpha (L^k)^{1-\alpha})^{\nu^k} \left((M^{ka})^{\mu^{ka}} (M^{km})^{\mu^{km}} (M^{ks})^{\mu^{ks}} \right)^{1-\nu^k}.$$

The term in parentheses captures the input-output linkages relating sector ℓ inputs used as intermediate inputs: $M^{k\ell}$, for $\ell \in \{a, m, s\}$, denotes the quantity of the composite good of type ℓ used by sector k as an input. K and L denote the quantities of capital and labor employed and constitute the value added factors of production. The parameter ν^k defines the ratio of value added to gross output, while $\mu^{k\ell}$ defines the share of the sector ℓ input in total intermediates.

Including such important features of the data in a structural change framework adds two additional channels for structural change. First, changes in sectoral final demand no longer propagate one-for-one into changes in sectoral employment or value-added. Rather, these changes propagate into different sectors depending on the extent of cross-sector input-output linkages. For example, if agriculture goods use services intensively, then an increase in demand for food will lead at least partly to an increased demand for services. Second, as shown in Sposi (2016), countries differ in the nature of their input-output linkages according to how rich they are. For example, richer countries use intermediate goods more intensively in the production of agriculture goods, and they use services more intensively in the production of all types of goods (agriculture, industry, and services). In other words, the same change in final demand for manufactured goods, for example, will result in changes in the manufacturing and other sectors' employment shares in an advanced economy that differ compared to the changes in an emerging market economy.

2.4.2 Labor “wedges”

By labor “wedges” we mean a policy, distortion, or some other friction that prevents marginal products of labor from being equalized across sectors. The sectoral reallocation of labor is, of course, at the heart of structural change, and virtually all models of structural change assume freely mobile labor. Given the long-run nature this research, it may not be a bad assumption, but, we will show later that the existence of such wedges is needed for the model to fit the data. All else equal, a higher wedge means a lower labor allocation relative to the value added generated in a sector.

2.4.3 Investment rates

Investment rates affect structural change primarily through final demand. To the extent that investment is comprised primarily of industry—manufacturing and construction—changes in aggregate investment rates will induce greater demand for industrial production and employment. Another notable feature of the data is that, recently, services has accounted for an increasing share of investment. So even with aggregate investment rates fixed, these feature could contribute to the rise in services value added and employment.

2.4.4 Trade imbalances

Trade imbalances, by definition, means that a country’s spending does not equal the value-added of its production. This means there is some “slippage” between changes in final demand and changes in the sectoral allocation of labor. In an extreme case, changes in domestic final demand could be met entirely with foreign factors of production with zero effect on domestic labor allocations.

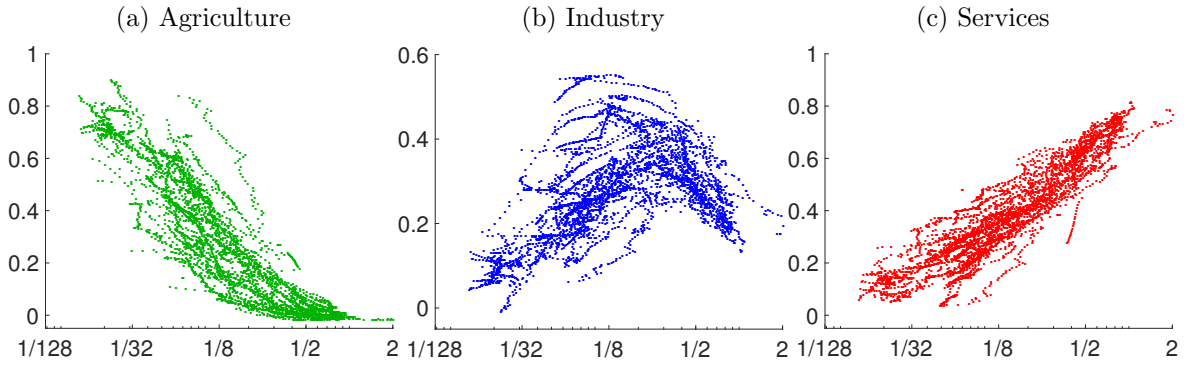
3 Structural change facts

We first present three broad facts about structural change. One is well-known and could be the single most important fact about structural change. The next two are relatively new. We then present facts that are particular to the three countries we focus on in our structural accounting decomposition: Hungary, Portugal, and South Korea.

3.1 Three broad structural change facts

Figure 1 plots the employment share across levels of income per capita (relative to the United States in 2011) for each sector. Our sample covers 41 countries and up to 110 years of data for some countries. For all countries, 2011 is the final year.⁴ The figure shows the well known fact that as countries develop the agriculture share of total employment and total value-added declines, the services share of total employment and value-added increases, and, for most countries, the industry (manufacturing+mining+utilities+construction) share of total employment and value-added follows a “hump” pattern.

Figure 1: Sectoral employment shares: 1970-2011



Notes: Horizontal axes - Real GDP per capita at PPP, relative to the United States in 2011.

To gain a better empirical understanding of the hump pattern in the industry employment share, we run the following regression:

$$empshr_{it} = \alpha_{it} + \sum_G [\beta_{G1} pci_{it} \mathbb{I}_{i \in G} + \beta_{G2} pci_{it}^2 \mathbb{I}_{i \in G}] + \epsilon_{it}, \quad (3)$$

where $empshr_{it}$ is the industry employment share in country i and year t , pci_{it} is the log per-capita income, and $\mathbb{I}_{i \in G}$ is an indicator for country i belonging to one of five country groups: Northern Europe, Other Advanced, Eastern Europe, Southern Europe, and Other Emerging Markets.⁵ We allow for different coefficients on the various country groups to explore the extent that there are similarities among middle-income countries of Eastern Europe and countries in other groups. We allow for country fixed effects. The time period for is 1950-2011 so as to focus on post-WWII patterns.

⁴See Appendix for list of countries and details on our data sources.

⁵See Appendix for assignment of countries to each group.

Table 1: Regression estimates

Country group	β_{G1}	(s.e.)	β_{G2}	(s.e.)
Eastern Europe	92.05	(5.21)	-5.31	(0.31)
Southern Europe	109.24	(7.50)	-6.10	(0.41)
Northern Europe	124.84	(7.17)	-7.05	(0.37)
Other advanced	121.11	(3.65)	-6.59	(0.20)
Emerging	-3.65	(4.22)	0.68	(0.26)

Table 1 shows the coefficient estimates on the log per-capita income terms. The table shows that for all but the emerging market sample (for which several countries have yet to peak), the coefficient on the linear term is positive and the coefficient on the quadratic term is negative.⁶ Moreover, the country group with the closest set of coefficients to those of Eastern Europe is Southern Europe.⁷ Finally, it is not surprising that northern European countries have similar coefficients to those of other advanced economies.

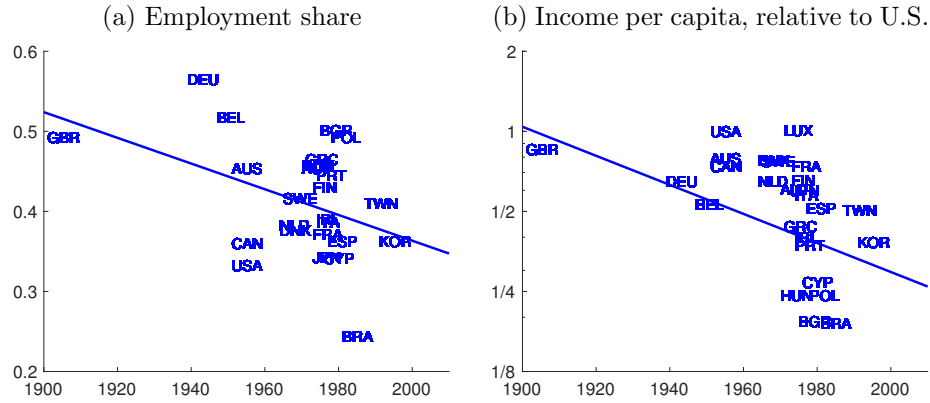
The second and third facts are about the share of employment in industry when that share peaks. Figure 2 contains two graphs. The first graph plots the peak level of the manufacturing employment share versus the year that the peak share was attained across our sample countries. The second graph plots the relative income level, vis-à-vis the United States, in the year that the peak occurred versus the year that the peak share was attained. Both graphs show a clear negative relation: Those countries that peak later tend to have a lower share of employment in industry at that peak. And those countries that tend to peak later have a lower per-capita income relative to U.S. in that year. These two facts are consistent with what Rodrik (2016) calls “premature deindustrialization”.

Regarding the three countries we will focus on later, Figure 2(a) show that Hungary and several other Eastern European countries had a relatively high employment share compared to South Korea when they peaked; see, for instance, Poland (POL) and Bulgaria (BGR). However, Figure 2(b) shows that Hungary and several other Eastern European countries had a relatively low per-capita income compared to South Korea when they peaked.

⁶The different coefficient signs for Emerging countries reflects the fact that many of these countries have not yet peaked in their manufacturing employment share, so the hump shape pattern is yet to play out.

⁷However, a statistical test of the null hypothesis that the two country groups have identical coefficients on the log per-capita income terms yields a rejection of the null hypothesis.

Figure 2: Patterns of Peak Industry Employment Shares



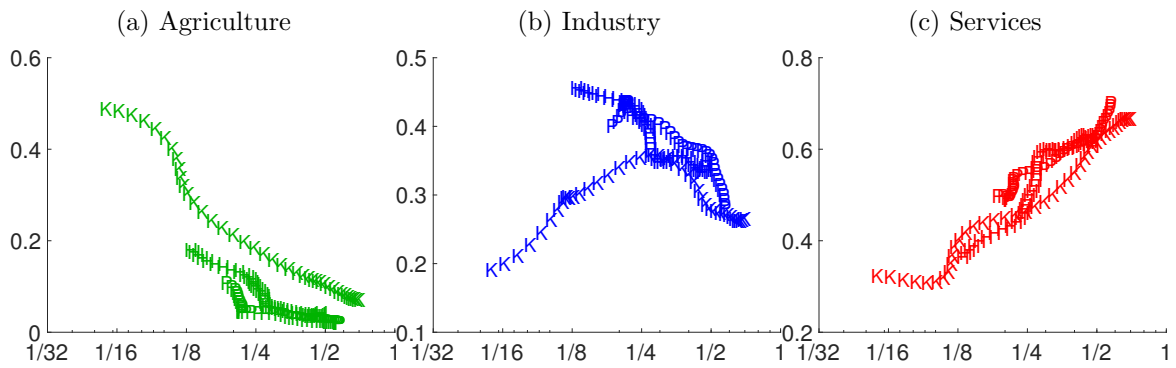
3.2 Structural change for Hungary, Portugal and South Korea

We now turn to the three countries that serve as the foci for our paper, Hungary, South Korea, and Portugal. All three countries fall in the one-third to two-thirds of U.S. PPP per-capita income range that the EBRD uses to discuss middle-income countries. Hungary is the Eastern European country with the most data availability, and experiences the transition from a command economy to a market system. South Korea is considered an economy that successfully transitioned from middle income to advanced economy status. Portugal is the Southern European country that is closest to Hungary in PPP per-capita income. This section includes a sequence of facts. In all but one of the figures, the data have been HP-filtered to remove business cycle fluctuations.

The first fact below shows the evolution of sectoral employment shares as the three countries developed. Hungary, South Korea, and Portugal are indicated with the letters H, K, and P, respectively, in Figure 3. The most striking aspect of the figure below involves the industry employment shares. Using Korea's pattern as a benchmark, the data show that both Portugal and Hungary had consistently higher industrial employment shares than Korea when it was at the same stage of per-capita income. In particular, Hungary's industry employment share has been declining at least since it reached about $\frac{1}{8}$ of U.S. per-capita income. For Portugal and South Korea, the decline began at higher levels of per-capita income. A key part of our wedge analysis below will be to understand why Hungary's industry employment share was significantly higher than Portugal's or South Korea's at relatively low levels of per-capita income.

Figure 4 plots real income per capita relative to the United States over time for Hungary,

Figure 3: Sectoral employment shares: 1970-2011



Notes: Horizontal axes - Real per capita GDP at PPP, relative to the United States in 2011.

South Korea, and Portugal. The graph shows of course, Korea's high growth performance, and it also illustrates that both Portugal and Hungary have had slowing trend growth in recent years with Portugal suffering a longer slowdown.

Figure 4: Real income per capita at PPP, relative to the United States in 2011

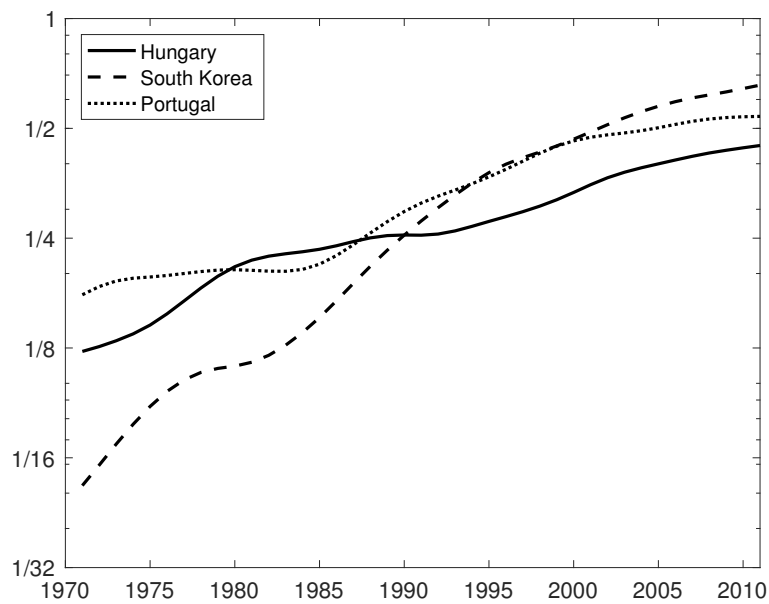
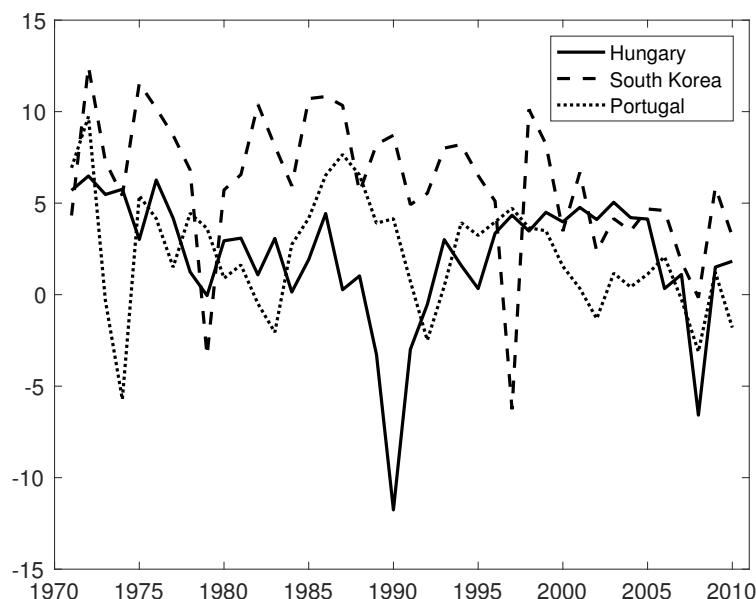


Figure 5 plots real income per capita growth over time for Hungary, South Korea, and Portugal. Note that this figure includes unfiltered growth rates of national accounts measures of real GDP. The figure illustrates just how much smoothing occurs with the HP-filtered data. For example, the deep recession in Hungary in 1990, and in South Korea in 1998, as well

as the Great Recession, are barely discernible in Figure 4. Again, our focus is on long-run trends.

Figure 5: Annual growth in real income per capita



The next two figures plot sectoral value-added shares and sectoral employment shares, respectively. Figure 6 plots each sector's share in aggregate GDP (value added shares) for Hungary, South Korea, and Portugal. Figure 7 plots each sector's share in aggregate employment (employment shares) for Hungary, South Korea, and Portugal. Focusing on the industry sector and on Hungary, both figures show a decline from the 1970s through the mid-1990s and the stable industry and employment-value added shares since then, in contrast to Portugal (decline in industry value-added and employment shares since the mid-1990s), and South Korea (decline in industry employment share since around 1990).

Figure 8 plots each sector's ratio of trade to value added (openness) for Hungary, South Korea, and Portugal. The key fact to point out is the surge in Hungary's openness in the industry sector since the early 1990s to the point that it has a higher share of trade to value-added than South Korea.

Figure 9 plots each sector's ratio of net exports to value added (imbalance) for Hungary, South Korea, and Portugal. There is a great deal of trend volatility, especially in agriculture and industry with Hungary running surpluses in agriculture and deficits in industry, while Portugal and South Korea have run deficits in agriculture, Portugal has tended to run a deficit in industry, and Korea has tended to run a surplus in industry.

Figure 6: Sectoral value added shares: 1970-2011

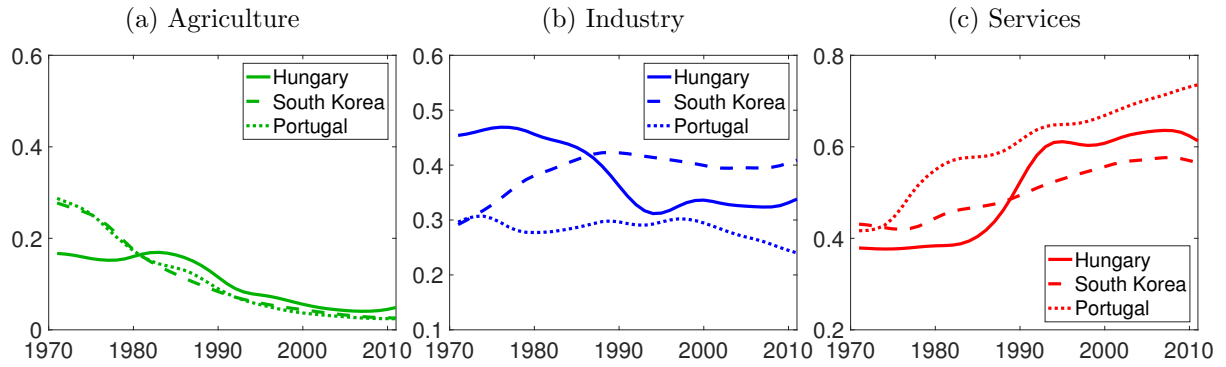


Figure 7: Sectoral employment shares: 1970-2011

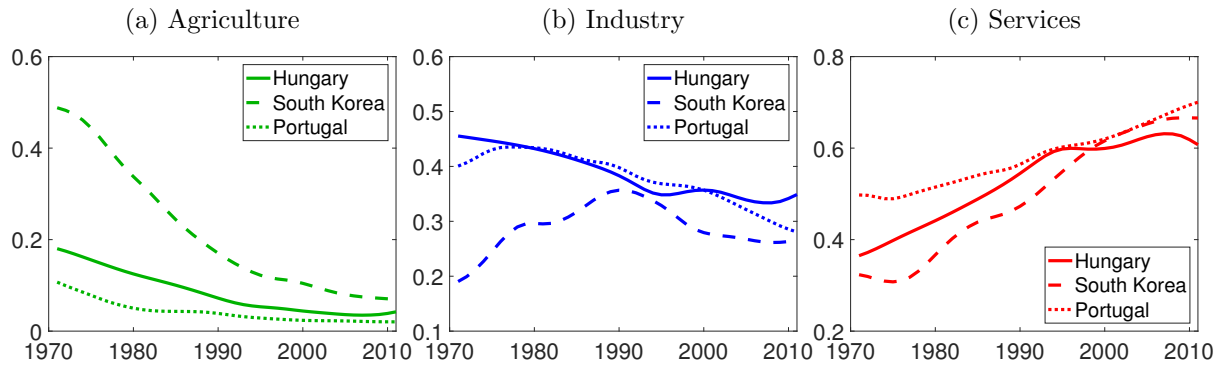
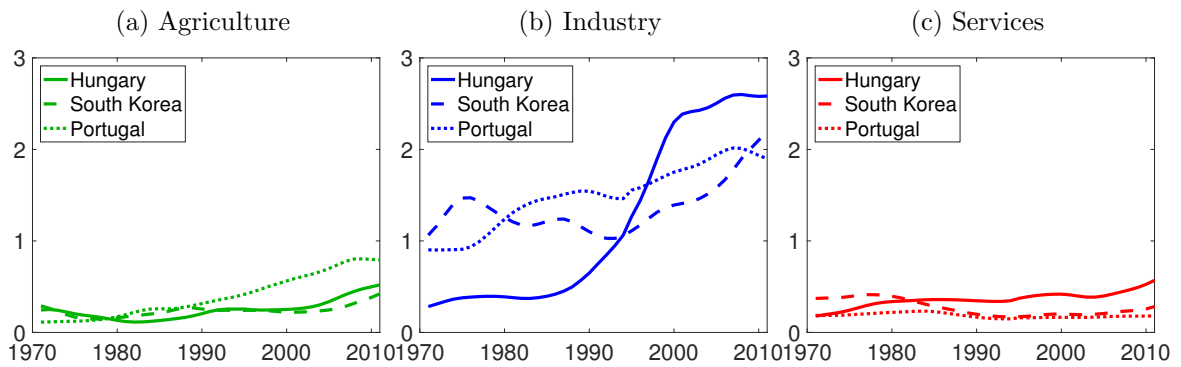
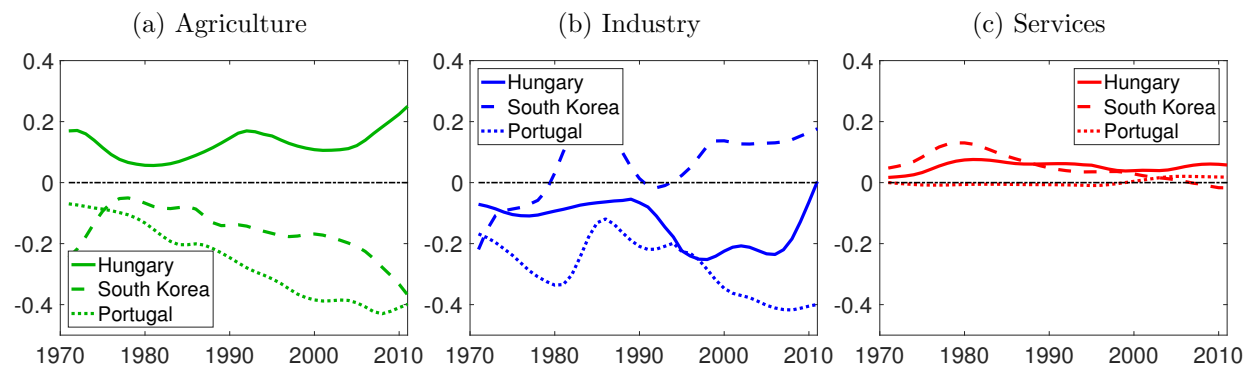


Figure 8: Sectoral openness: 1970-2011



Notes: Openness is defined as the ratio of imports plus exports to value added within each sector.

Figure 9: Sectoral trade imbalances: 1970-2011



Notes: Imbalances are defined as the ratio of exports minus imports to value added in each sector.

4 Model

We now describe the model we use for our structural accounting exercises. We employ a three-sector, multi-country, Ricardian model of trade along the lines of Uy, Yi, and Zhang (2013), Świecki (2014), and Sposi (2016). There are N countries indexed by $(i, j) = 1, \dots, I$ and three sectors: agriculture, industry, and services, denoted by $(k, \ell) \in \{a, m, s\}$ respectively. Time is discrete and runs from $t = 1, \dots, T$.

4.1 Endowments

Each country is inhabited by a representative household. The representative household in country i consists of a labor force of size L_{it} at time t that it supplies inelastically to all domestic firms.

4.2 Technology

There is a unit interval of varieties in each sector. Each variety within each sector is tradable and is indexed by $x_b \in [0, 1]$ for $b \in \{a, m, s\}$.

Composite goods Within each sector, all of the varieties are combined with constant elasticity in order to construct a sectoral composite good according to

$$Q_{it}^k = \left[\int q_{it}^k(x_k)^{1-1/\eta} dx_k \right]^{\eta/(\eta-1)},$$

where η is the elasticity of substitution between any two varieties and is constant across countries, across sectors, and over time.⁸ The term $q_{it}^k(x_k)$ is the quantity of variety x_k used by country i at time t to construct the sector k composite good. The resulting composite good, Q_{it}^k , is the quantity of the sector k composite good available in country i to use either as an intermediate input or for final consumption at time t .

Individual varieties Each individual variety is produced using labor and intermediate (composite) goods from each sector. The technologies for producing each variety in each

⁸The value η plays no quantitative role other than ensuring convergence of the integrals.

sector are given by

$$Y_{it}^k(x_k) = z(x_k) (T_{it}^k K_{it}^k(x_k)^\alpha L_{it}^k(x_k)^{1-\alpha})^{\nu_{it}^k} \left(\prod_{\ell \in \{a, m, s\}} M_{it}^{k\ell}(x_b)^{\mu_{it}^{k\ell}} \right)^{1-\nu_{it}^k}.$$

The term $M_{it}^{k\ell}(x_k)$, for $(k, \ell) \in \{a, m, s\}$, denotes the quantity of the composite good of type ℓ used by country i as an input to produce variety x_k at time t . Similarly, $K_{it}^k(x_k)$ and $L_{it}^k(x_k)$ denote the quantities of capital and labor employed. Capital's share in value added, α , is constant across countries and over time. The parameter $\nu_{it}^k \in [0, 1]$, for $k \in \{a, m, s\}$, denotes the share of value added in total output in sector k , while $\mu_{it}^{k\ell} \in [0, 1]$ denotes the share of composite good ℓ in total spending on intermediates by producers in sector k , with $\sum_\ell \mu_{it}^{k\ell} = 1$ at all t . Each of these coefficients is country-specific and varies over time.

Value-added productivity is given by T_{it}^k , specific to a country-year-sector. The term $z(x_k)$ denotes country i 's idiosyncratic productivity for producing variety x_k . Following Eaton and Kortum (2002), the idiosyncratic draw comes from independent Fréchet distributions with shape parameters θ^k for $k \in \{a, m, s\}$, with c.d.f. given by $F_{it}^k(z) = \exp(-z^{-\theta^k})$. Once the vector of cost draws is known, the actual index of the variety becomes irrelevant.

4.3 Labor market wedges

Workers are homogenous within a country and take home a common wage rate, w_{it} regardless of the sector that they work in. All firms hire from the same domestic market but face sector-specific wedges. Specifically, firms in sector k pay $(1 + \lambda_{it}^k)w_{it}$. As a normalization, we assume that there is no distortion in manufacturing; $\lambda_{it}^m = 0$. For instance, labor-embodied productivity, such as human capital, may differ across sectors and workers must be compensated accordingly to remain indifferent between working in each sector. Compensating differentials are returned in lump sum to the household.

4.4 Trade

All international trade is subject to barriers that take the iceberg form. Country i must purchase $d_{ijt}^k \geq 1$ units of any individual variety of sector k from country j in order for one unit to arrive at time t ; $d_{ijt}^k - 1$ units *melt* away in transit. The trade barriers vary across sectors and over time. As a normalization we assume that $d_{iit}^k = 1$ for all (k, i) .

4.5 Preferences

Aggregate consumption is a Cobb-Douglas over agriculture and non-agriculture, with Stone-Geary subsistence requirement for agriculture. Consumption of the non-agricultural composite is implicitly a generalized, non-homothetic CES over manufacturing and services along the lines of Comin, Lashkari, and Mestieri (2015).

$$C_{it} = (C_{it}^a - L_{it}\bar{c}^a)^{\omega_{it}^{C^a}} (C_{it}^N)^{1-\omega_{it}^{C^a}}$$

$$\sum_{k \in \{m,s\}} \omega_{it}^{C^k} \left(\frac{C_{it}^N}{L_{it}} \right)^{\frac{\varepsilon^k - \sigma}{\sigma}} \left(\frac{C_{it}^k}{L_{it}} \right)^{\frac{\sigma-1}{\sigma}} = 1.$$

Aggregate *discretionary* (non-subsistence) consumption is denoted by C_{it} . Total consumption is given by $C_{it} + L_{it}\bar{c}^a$, where $\bar{c}^a$ is the per-capita subsistence requirement of agriculture. Total agricultural consumption is denoted by C_{it}^a , and C_{it}^N is the non-agricultural consumption composite, which bundles consumption of both manufacturing and services, C_{it}^m and C_{it}^s , respectively. The parameter $\omega_{it}^{C^a} \in [0, 1]$ determines the share of consumption expenditures on discretionary agricultural consumption in country i at time t . Within the non-agricultural composite, the term $\sigma > 0$ governs the elasticity of substitution between the manufacturing and services, while ε^m and ε^s denote the income elasticities for each good; each of which is constant across countries and over time. Finally, $\omega_{it}^{C^m}$ and $\omega_{it}^{C^s} (= 1 - \omega_{it}^{C^m})$ denote the relative weights of each good within the bundle.

4.6 Saving technologies

National saving is incorporated by allowing for investment and net exports. Both components of saving are introduced in a tractable manner as we describe below, thereby providing the model with additional flexibility to replicate national accounts data.

Investment First, we define aggregate investment, X_{it} , as a Cobb-Douglas aggregate of each sector's composite good:

$$X_{it} = \prod_{k \in \{a,m,s\}} (X_{it}^k)^{\omega_{it}^{X^k}}.$$

An exogenous share of income, ρ_{it} , is allocated to investment spending. Household income equals capital and labor income plus transfers from the labor market distortions: $w_{it}L_{it} +$

$r_{it}K_{it} + R_{it}^G$. Denote the ideal price index for a bundle of investment goods by P_{it}^X , then

$$P_{it}^X X_{it} = \rho_{it}(w_{it}L_{it} + r_{it}K_{it} + R_{it}^G),$$

Aggregate investment augments the existing stock of capital subject one-period time to build with linear depreciation:

$$K_{it+1} = (1 - \delta)K_{it} + X_{it}.$$

Although the nominal investment rate is exogenous, the real investment rate is endogenous since it depends on relative price of investment.

International saving Households borrow from (lend to) the rest of the world by running trade deficits (surpluses). Trade imbalances are modeled as proceeds from a global portfolio as in Caliendo, Parro, Rossi-Hansberg, and Sarte (2014). A pre-determined share of income, ϕ_{it} , is sent to a global portfolio. The global portfolio disperses a lump sum transfer, $L_{it}R_t^P$, to every country, where R_t^P is the per-capita transfer at time t common to all countries. While the share of income allocated to the global portfolio is exogenous, the proceeds are endogenous, because they depend of the size of the global portfolio. Therefore, the overall trade imbalance is endogenous, both in terms of absolute level and as shares of local and global GDP.

4.7 Budget constraint

The household spends its income on consumption and investment in the three goods; the period budget constraint is

$$\underbrace{\sum_{k \in \{a, m, s\}} P_{it}^k C_{it}^k}_{P_{it}^C (C_{it} + L_{it} \bar{c}^a)} + \underbrace{\sum_{k \in \{a, m, s\}} P_{it}^k X_{it}^k}_{P_{it}^X X_{it}} = (1 - \phi_{it})(w_{it}L_{it} + r_{it}K_{it} + R_{it}^G) + L_{it}R_t^P,$$

where ϕ_{it} is the share of income sent to the global portfolio. The proceeds from the global portfolio are given by $L_{it}R_t^P$ implying that country i 's net exports, the difference between household income and final expenditures is $\phi_{it}(w_{it}L_{it} + r_{it}K_{it} + R_{it}^G) - L_{it}R_t^P$. The ideal price indices for consumption and investment are P_{it}^C and P_{it}^X , respectively.

4.8 Equilibrium

A competitive equilibrium satisfies the following conditions: 1) the representative household maximizes utility taking prices as given, 2) firms maximize profits taking prices as given, 3) each country purchases each variety from its least-cost supplier, and 4) markets clear. We describe each equilibrium condition in detail below and omit time subscripts to simplify notation. (Table B.1 in Appendix B lists the equations for all of the equilibrium conditions.)

4.8.1 Household optimization

Household take income as given. The income is allocated across net lending to the world, investment in the three sectors, and consumption in the three sectors.

Saving and investment A predetermined share of income, ϕ_{it} , is sent to the global portfolio. Another predetermined share of income, ρ_{it} , is spent on investment. Investment spending is allocated across sectors as

$$P_{it}^k X_{it}^k = \omega_{it}^{Xk} P_{it}^X X_{it}.$$

Consumption Income that is not saved is allocated toward consumption expenditures. The problem of allocating consumption across the three sectors can be broken down into three steps. First, given aggregate consumption spending, consumption of agriculture is given by

$$C_{it}^a = \frac{\omega_{it}^{Ca} (P_{it}^C C_{it} - L_{it} P_{it}^a \bar{c}^a) + L_{it} P_{it}^a \bar{c}^a}{P_{it}^a} \quad (4)$$

Second, given the non-agricultural consumption demand and corresponding ideal price index satisfy the following two simultaneous equations:

$$C_{it}^N = \frac{(1 - \omega_{it}^{Ca}) (P_{it}^C C_{it} - L_{it} P_{it}^a \bar{c}^a)}{P_{it}^N}$$

$$P_{it}^N = \left(\sum_{k \in \{m,s\}} (\omega_{it}^{Ck})^\sigma \left(\frac{C_{it}^N}{L_{it}} \right)^{\varepsilon_k - 1} (P_{it}^k)^{1 - \sigma} \right)^{\frac{1}{1 - \sigma}}.$$

Third, taking non-agricultural consumption and the corresponding ideal price index as

given, the sectoral demand for consumption of manufacturing and services satisfies

$$C_{it}^k = L_{it}(\omega_{it}^{C^k})^\sigma \left(\frac{P_{it}^k}{P_{it}^N} \right)^{-\sigma} \left(\frac{C_{it}^N}{L_{it}} \right)^{\varepsilon^k}.$$

4.8.2 Firm optimization

Markets are perfectly competitive, so firms set prices equal to marginal costs. Denote the price of variety z^k , produced in country j and purchased by country i , as $p_{ijt}^k(z_b)$. Then $p_{ijt}^k(z^k) = p_{jjt}^k(z^k)d_{ijt}^k$, where $p_{jjt}^k(z^k)$ is the marginal cost of producing variety z^k in country j . Since country i purchases each variety from the country that can deliver it at the lowest price, the price in country i is $p_{it}^k(z^k) = \min_{j=1,\dots,I} [p_{jjt}^k(z^k)d_{ijt}^k]$. The price of the sector k composite good in country i is then

$$P_{it}^k = \gamma_k \left[\sum_{j=1}^I \left((T_{jt}^k)^{-\nu_j^k} u_{jt}^k d_{ijt}^k \right)^{-\theta^k} \right]^{-\frac{1}{\theta^k}}, \quad (5)$$

where the unit cost for a bundle of inputs for producers in sector k in country i is

$$u_{it}^k = \left(\frac{r_i}{\alpha \nu_{it}^k} \right)^{\alpha \nu_{it}^k} \left(\frac{(1 + \lambda_i^k) w_{it}}{(1 - \alpha) \nu_{it}^k} \right)^{(1 - \alpha) \nu_{it}^k} \left[\prod_{\ell \in \{a, m, s\}} \left(\frac{P_{it}^\ell}{\mu_{it}^{k\ell}} \right)^{\mu_{it}^{k\ell}} \right]^{1 - \nu_{it}^k}. \quad (6)$$

Next we define total factor usage in sector k by aggregating the individual varieties.

$$\begin{aligned} K_{it}^k &= \int K_{it}^k(x^k) dx^k, & L_{it}^k &= \int L_{it}^k(x^k) dx^k, \\ M_{it}^{k\ell} &= \int M_{it}^{k\ell}(x^k) dx^k, & Y_{it}^k &= \int Y_{it}^k(x^k) dx^k. \end{aligned}$$

The term $K_{it}^k(x^k)$ denotes the quantity of labor used in the production of variety x^k . If country i imports variety x^k , then $K_{it}^k(x^k) = 0$. Hence, K_{it}^k is the total capital used in sector k in country i . Similarly, L_{it}^k is the total quantity of labor used, $M_{it}^{k\ell}$ denotes the quantity of good ℓ that country i uses as an intermediate input in production in sector k , and Y_{it}^k is the quantity of the sector k output produced by country i .

Cost minimization by firms operating under constant returns to scale implies that, within

each sector, factor expenses exhaust the value of output:

$$\begin{aligned} r_{it}K_{it}^k &= \alpha\nu_{it}^k P_{it}^k Y_{it}^k, \\ (1 + \lambda_{it}^k)w_{it}L_{it}^k &= (1 - \alpha)\nu_{it}^k P_{it}^k Y_{it}^k, \\ P_{it}^\ell M_{it}^{k\ell} &= (1 - \nu_{it}^k)\mu_{it}^{k\ell} P_{it}^k Y_{it}^k. \end{aligned}$$

4.8.3 Trade flows

In sector k the fraction of country i 's expenditures allocated to goods produced by country j is given by

$$\pi_{ijt}^k = \frac{\left((T_{jt}^k)^{-\nu_{it}^k} u_j^k d_{ijt}^k\right)^{-\theta^k}}{\sum_{h=1}^I \left((T_{ht}^k)^{-\nu_{ht}^k} u_{ht}^k d_{iht}^k\right)^{-\theta^k}}. \quad (7)$$

4.8.4 Market clearing conditions

We begin by describing the domestic market clearing conditions:

$$\begin{aligned} K_{it} &= \sum_{k \in \{a, m, s\}} K_{it}^k, \\ L_{it} &= \sum_{k \in \{a, m, s\}} L_{it}^k, \\ Q_{it}^k &= C_{it}^k + X_{it}^k + \sum_{\ell \in \{a, m, s\}} M_{it}^{\ell k}. \end{aligned}$$

The first two conditions impose capital and labor market clearing in country i . The third condition, which applies to sac sector $k \in \{a, m, s\}$, requires that the use of composite good k equal its supply. Its use consists of consumption and investment by the representative household and intermediate use by firms in each sector. Its supply is the quantity of the composite good, which consists of both domestically- and foreign-produced varieties.

The next conditions require that the value of output produced by country i is equal to the value that all countries purchase from country i . That is,

$$P_{it}^k Y_{it}^k = \sum_{j=1}^I \left(P_{it}^k C_{it}^k + P_{it}^k X_{it}^k + \sum_{\ell \in \{a, m, s\}} P_{it}^k M_{it}^{\ell k} \right) \pi_{ijt}^k. \quad (8)$$

Finally we impose an aggregate resource constraint in each country: the sum of net

exports across sectors must equal the value of net lending.

$$\phi_{it}(w_{it}L_{it} + r_{it}K_{it} + R_{it}^G) - L_{it}R_t^P = \sum_{k \in \{a,m,s\}} P_{it}^k Y_{it}^k - P_{it}^k Q_{it}^k. \quad (9)$$

The left-hand side is the difference between the household's income and spending. The right-hand side is the value of gross production minus gross absorption. In equilibrium, both sides must equal net exports.

5 Measurement and calibration of “wedges”

In this section, we first describe how we set the parameters that are common across sectors or countries. Then, we present how we determine each of the seven sets of country and/or sector-specific, as well as time-varying parameters and exogenous shocks. We will call the time-varying parameters and exogenous shocks “wedges”.

5.1 Common parameters

Table 2 reports the parameters that are common across countries and constant over time. Starting with the preferences parameters, we choose the subsistence level, $\bar{c}^a$, so that the maximum ratio of subsistence to agricultural consumption is 0.75. From Lewis, Monarch, Sposi, and Zhang (2018), we take $\sigma = 0.39$, $\varepsilon^m = 1$ (normalization), and $\varepsilon^s = 1.40$. They estimate these parameters in a model with preferences defined over goods and services using a similar set of countries over a similar time period. In their model, goods include both agriculture and manufacturing.

Next we describe the production parameters. Capital's share in value added is set to $\alpha = 0.33$ as in Gollin (2002). The depreciation rate is set to $\delta = 0.06$, as is standard in macro models using annual data. Simonovska and Waugh (2014) estimate the trade elasticity for manufacturing to be 4. We apply this estimate to all sectors and set $\theta^k = 4$ in each sector. The elasticity of substitution between individual goods within the composite good plays no quantitative role in the model other than satisfying a technical condition: $1 + \frac{1}{\theta_b}(1 - \eta) > 0$. Following the literature we set $\eta = 2$.

Table 2: Common parameters

$\bar{c}^a$	Per-capita subsistence level of agriculture consumption	1.55×10^{-6}
σ	Elasticity of substitution between industry and services consumption	0.39
ε^m	Income elasticity of demand for industry consumption	1
ε^s	Income elasticity of demand for services consumption	1.40
α	Capital's share in value added	0.33
δ	Annual depreciation rate for stock of capital	0.06
θ^k	Trade elasticity	4
η	Elasticity of substitution between varieties	2

Notes: The per-capita subsistence, $\bar{c}^a$, implies that the subsistence share in U.S. agriculture consumption is 0.15 in 2011. The model's units are normalized so that world labor compensation equals 1 in every period:

$$\sum_{i=1}^I w_{it} L_{it} = 1, \forall t.$$

5.2 Country-specific and time-varying exogenous variables and parameters

As a reminder, the exogenous variables and time varying parameters, i.e., the wedges, that we back out from the data through the lens of the model are:

1. Total factor (fundamental) productivity: T_{it}^k
2. Trade barriers: d_{ijt}^k
3. Preference shocks: ω_{it}^{Ca}
4. Labor market wedges: λ_{it}^k
5. Value-added and input-output coefficients: ν_{it}^k and $\mu_{it}^{k\ell}$
6. Investment rates and sectoral investment shares: ρ_{it} and ω_{it}^{Xk}
7. Trade imbalance shares: ϕ_{it}

These wedges are “chosen” by the model to match the following data moments: sectoral value added, sectoral bilateral trade shares, sectoral consumption expenditures, sectoral employment, sectoral gross production and intermediate-input usage, sectoral investment expenditures, and aggregate trade imbalances. In what follows below, “hats” on variables refer to data. We also make use of data on aggregate employment in each country and the initial stock of capital in each country.

Fundamental productivity Sectoral productivity can be recovered from the sectoral prices. Using equations (5) and (7), the price of the sector k composite good can be expressed as $P_{it}^k = \frac{u_{it}^k}{Z_{it}^k}$, where u_{it}^k denotes the unit cost for a bundle of inputs in sector k and Z_{it}^k denotes the measured productivity. Expanding out for the unit costs and rearranging, the measured productivity can be backed out as

$$Z_{it}^k = \left(\frac{1}{\widehat{P}_{it}^k} \right) \left(\frac{r_{it}}{\alpha \nu_{it}^k} \right)^{\alpha \nu_{it}^k} \left(\frac{(1 + \lambda_{it}^k) \widehat{w}_{it}}{(1 - \alpha) \nu_{it}^k} \right)^{(1 - \alpha) \nu_{it}^k} \left[\prod_{\ell \in \{a, m, s\}} \left(\frac{\widehat{P}_{it}^\ell}{\mu_{it}^{k\ell} (1 - \nu_{it}^k)} \right)^{\mu_{it}^{k\ell}} \right]^{1 - \nu_{it}^k}. \quad (10)$$

Sector prices, $\widehat{P}^k$, are read directly from the data. The aggregate wage is taken from the data as the aggregate value added per worker, $\widehat{w}_{it} = \frac{\widehat{VA}_{it}}{\widehat{L}_{it}}$. The labor wedges, $\widehat{\lambda}^k$, are computed above using equation (17). The production elasticities, ν_{it}^k and $\mu_{it}^{k\ell}$ are computed above using equations (18) and (19). This leaves the unobserved rental rate for capital, r_{it} , which we impute using the model's structure and data on aggregate capital stocks.

In the model, cost minimization by firms implies that $\frac{(1 + \lambda_{it}^k) w_{it} L_{it}^k}{1 - \alpha} = \frac{r_{it} K_{it}^k}{\alpha}$ in each sector. Aggregating across sectors and imposing market clearing for capital— $K_{it} = \sum_{k \in \{a, m, s\}} K_{it}^k$ —implies that the rental rate can be imputed as

$$r_{it} = \left(\frac{\widehat{w}_{it}}{\widehat{K}_{it}} \right) \left(\frac{1 - \alpha}{\alpha} \right) \sum_{k \in \{a, m, s\}} (1 + \lambda_{it}^k) \widehat{L}_{it}^k.$$

The aggregate capital stock, $\widehat{K}_{it}$ is taken directly from the data.

Given the measured productivity, Z_{it}^k , the fundamental productivity is recovered using data on sectoral home trade shares:

$$T_{it}^k = \left(\gamma^k Z_{it}^k (\widehat{\pi}_{iit}^k)^{\frac{1}{\theta^k}} \right)^{\frac{1}{\nu_{it}^k}} \quad (11)$$

Bilateral trade barriers Through the lens of the model, the bilateral trade barrier between two countries appears as a wedge that reconciles the pattern of trade between them, taking the prices in both countries as given.

$$d_{ijt}^k = \left(\frac{\widehat{\pi}_{ijt}^k}{\widehat{\pi}_{jtt}^k} \right)^{-\frac{1}{\theta^k}} \left(\frac{\widehat{P}_{it}^k}{\widehat{P}_{jt}^k} \right) \quad (12)$$

For each sector $k \in \{a, m, s\}$, we make use of the data on bilateral trade shares, $\hat{\pi}_{ijt}^k$, and prices, $\hat{P}_{it}^k$, to compute the bilateral trade barriers directly. In cases where $\hat{\pi}_{ijt}^k = 0$ in the data, we set $d_{ij}^k = 10^8$ (this is arbitrarily large enough to ensure that $\pi_{ijt}^k \approx 0$ in the model). In cases where the computed barrier is less than 1, we set $d_{ijt}^k = 1$.

Preference weights Calibration of the preference weights makes use of data on sectoral consumption expenditures and prices. Denote the consumption expenditures in sector k as $E_{it}^{Ck} = P_{it}^k C_{it}^k$. The preference weight for agriculture is computed as

$$\frac{\omega_{it}^{Ca}}{1 - \omega_{it}^{Ca}} = \frac{\hat{E}_{it}^{Ca} - \hat{L}_{it} \hat{P}_{it}^a \bar{C}^a}{\hat{E}_{it}^{Cm} + \hat{E}_{it}^{Cs}} \quad (13)$$

The preference weights for manufacturing and services can be identified off of data on relative expenditures, relative prices, and non-agricultural consumption levels. Noting that $\omega_{it}^{Cs} = 1 - \omega_{it}^{Cm}$,

$$\frac{\hat{E}_{it}^{Cm}}{\hat{E}_{it}^{Cs}} = \left(\frac{\omega_{it}^{Cm}}{\omega_{it}^{Cs}} \right)^\sigma \left(\frac{\hat{P}_{it}^{cm}}{\hat{P}_{it}^{cs}} \right)^{1-\sigma} \left(\frac{C_{it}^N}{\hat{L}_{it}} \right)^{\varepsilon^m - \varepsilon^s} \quad (14)$$

We impute the level of non-agricultural consumption bundle using the observed prices and levels of consumption of manufactures and services in addition to the level of non-agricultural consumption expenditures as dictated by the model.

$$\frac{\hat{E}_{it}^{Cm} + \hat{E}_{it}^{Cs}}{\hat{L}_{it}} = \left(\sum_{k \in \{m, s\}} (\omega_{it}^{Ck})^\sigma \left(\frac{C_{it}^N}{\hat{L}_{it}} \right)^{\varepsilon^k - \sigma} (\hat{P}_{it}^k)^{1-\sigma} \right)^{\frac{1}{1-\sigma}}. \quad (15)$$

Solving for equations (15) and (14) jointly given the manufacturing preference weights and the level of non-agricultural consumption. The price level for nonagricultural consumption is defined as the ratio of nominal expenditures to the level of consumption:

$$P_{it}^N = \frac{\hat{E}_{it}^{Cm} + \hat{E}_{it}^{Cs}}{C_{it}^N}. \quad (16)$$

Labor endowments and labor market wedges L_{it} are computed directly from data as the numbers of persons engaged across the three broad sectors.

The labor market wedges are defined to reconcile the disparity between sectoral employment shares and sectoral value added shares. In the model, sector k value added is $(1 + \lambda_{it}^k) w_{it} L_{it}^k + r_{it} K_{it}^k$. Moreover, in each sector the capital-labor ratio is given by

$\frac{K_{it}^k}{L_{it}^k} = \frac{\alpha}{1-\alpha} \frac{(1+\lambda_{it}^k)w_{it}}{r_{it}}$. This implies that sector k value added equals $\frac{(1+\lambda_{it}^k)w_{it}L_{it}^k}{1-\alpha}$. By normalizing the manufacturing labor wedge, $\lambda_{it}^m = 0$, the wedge in sector k is computed as

$$1 + \lambda_{it}^k = \frac{\widehat{VA}_{it}^k / \widehat{VA}_{it}^m}{\widehat{L}_{it}^k / \widehat{L}_{it}^m}. \quad (17)$$

Value-added and Input-output coefficients In the model, ν_{it}^k is the share of gross output that compensates capital and labor: $\frac{(1+\lambda_{it}^k)w_{it}+r_{it}K_{it}^k}{P_{it}^k Y_{it}^k}$. We compute it directly as the ratio of value added, VA , to gross output, GO , in each sector-country-year:

$$\nu_{it}^k = \frac{\widehat{VA}_{it}^k}{\widehat{GO}_{it}^k}. \quad (18)$$

The intermediate input share $\mu_{it}^{k\ell}$ is the share of the sector ℓ in intermediates in sector k : $\frac{P_{it}^\ell M_{it}^{k\ell}}{\sum_{b \in \{a,m,s\}} P_{it}^b M_{it}^{kb}}$. We compute it as the ratio of sector k 's spending on inputs from sector ℓ , $IO^{k\ell}$, to sector k 's total spending on intermediate inputs (gross output net of value added).

$$\mu_{it}^{k\ell} = \frac{\widehat{IO}_{it}^{k\ell}}{\widehat{GO}_{it}^k - \widehat{VA}_{it}^k}. \quad (19)$$

Note that $\sum_{\ell \in \{a,m,s\}} \mu_{it}^{k\ell} = 1$, for all (k, i, t) , since $\widehat{GO}_{it}^k = \widehat{VA}_{it}^k + \sum_{\ell \in \{a,m,s\}} \widehat{IO}_{it}^{k\ell}$.

Investment rates The nominal investment rate in the model is given by $\rho_{it} = \frac{P_{it}^X X_{it}}{w_{it}L_{it} + r_{it}K_{it} + R_{it}^G}$. We compute it as the ratio of gross fixed capital formation, $GFCF$, to aggregate gross domestic product, GDP :

$$\rho_{it} = \frac{\widehat{GFCF}_{it}}{\widehat{GDP}_{it}}. \quad (20)$$

Each sector's share in aggregate investment is given by $\omega_{it}^{Xk} = \frac{P_{it}^k X_{it}^k}{P_{it}^X X_{it}}$. We compute it as the ratio of investment expenditures on goods from sector k , $GFCF^k$ to aggregate investment expenditures:

$$\omega_{it}^{Xk} = \frac{\widehat{GFCF}_{it}^k}{\widehat{GFCF}_{it}}. \quad (21)$$

Trade Imbalances In the baseline model we assume that transfers from the global portfolio, R^G are equal to 0, so that the fraction of income located to the global portfolio is equals ratio of net exports to GDP is $\phi_{it} = \frac{w_{it}L_{it}+r_{it}K_{it}+R_{it}^G-P_{it}^C C_{it}-P_{it}^X X_{it}}{w_{it}L_{it}+r_{it}K_{it}+R_{it}^G}$ (the numerator is equal to net exports, NX). Thus, we have

$$\phi_{it} = \frac{\widehat{NX}_{it}}{\widehat{GDP}_{it}}. \quad (22)$$

In the data we ensure that $\sum_{i=1}^I \widehat{NX}_{it} = 0$ so the global portfolio is balanced in every year.

5.3 Calibrated wedges

The previous sub-section described how we back out the seven sets of wedges, with each wedge corresponding to a mechanism for structural change, using data and the model.⁹ We now show a subset of the wedges. In the interest of brevity, we highlight the most important wedges for each of the three countries, which are the first four of the above wedges.

Productivity Figure 10 plots the fundamental productivity level, T_{it}^k , over time for each of the three sectors. The sectoral productivities are normalized to that of the U.S. in 2011. In all three countries, agriculture productivity rose fairly steadily over the sample period, and services productivity has grown little or even declined since 1990. In industry, Hungary is an outlier in the post 1990 period in that its productivity stayed relatively flat, while South Korea's productivity increased substantially and Portugal exhibited a hump pattern.¹⁰

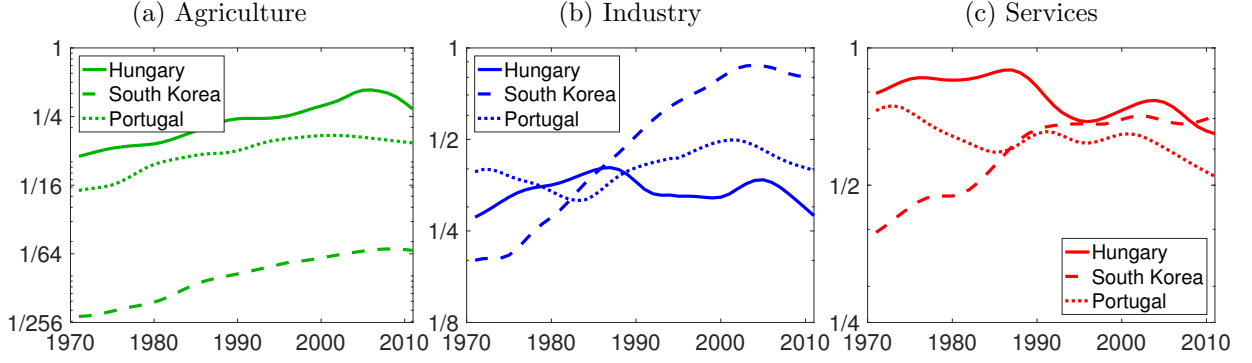
Trade barriers The next two figures plot the sectoral import and export barriers, respectively. Through the lens of the model these barriers are wedges that are needed to reconcile the observed pattern of bilateral trade given the levels of technology. They therefore capture both policy and non-policy impediments to trade.

Figure 11 plots the bilateral-trade-weighted-average import barrier, $\sum_{j \neq i} d_{ijt}^k \frac{Trd_{ijt}^k}{Imp_{it}^k}$, over time for each sector, where Trd_{ijt}^k is the value of sector k trade flows from country j to country i at time t and Imp_{it}^k is the value of country i sector k imports. In the industrial

⁹As a reminder, our data are HP-filtered to remove the business cycle frequencies; the HP-filtered data are used to back out the wedges. Hence, the wedges capture only secular trends over time.

¹⁰Note that the Great Recession shows up as declines in productivity, especially in industry, in the last few years of the period.

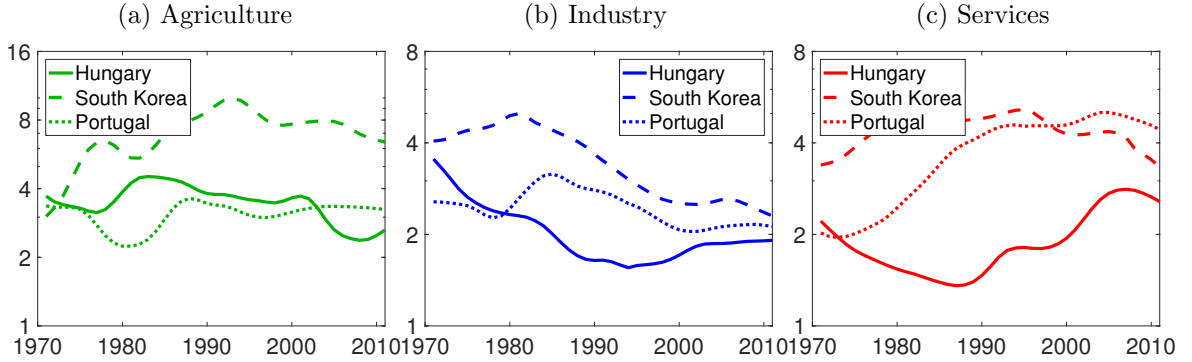
Figure 10: Sectoral productivity: 1970-2011



Notes: Vertical axes are fundamental value-added productivity T_{it}^k .

sector, there is a broad downward trend so that all three countries have roughly the same barrier by 2011. For services, the import barriers in Hungary and Portugal rose over time, while that of South Korea stayed about the same. In agriculture, the import barriers in Hungary and Portugal stayed about the same, while they rose in South Korea.

Figure 11: Sectoral import barrier: 1970-2011

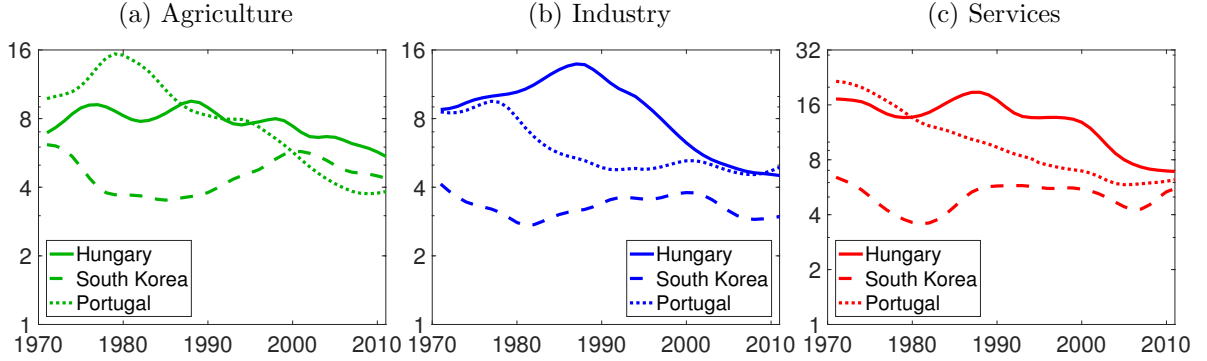


Notes: Vertical axes - Trade bilateral-trade-weighted import barrier: $\sum_{j \neq i}^I d_{ijt}^k \frac{Trd_{ijt}^k}{Imp_{it}^k}$, over time, where Trd_{ijt}^k is the value of sector k trade flows from country j to country i at time t and Imp_{it}^k is the value of country i sector k imports.

Figure 12 plots the bilateral-trade-weighted-average export barrier, $\sum_{j \neq i}^I d_{jit}^k \frac{Trd_{jit}^k}{Exp_{it}^k}$, over time for each sector, where Trd_{jit}^k is the value of sector k trade flows from country i to country j at time t and Exp_{it}^k is the value of country i sector k exports. The broad trend for Hungary and Portugal is one of decline for all sectors and the entire four decade period,

although there are low frequency fluctuations within the period. The export barriers for Korea are roughly unchanged over the sample period for all sectors.

Figure 12: Sectoral export barrier: 1970-2011

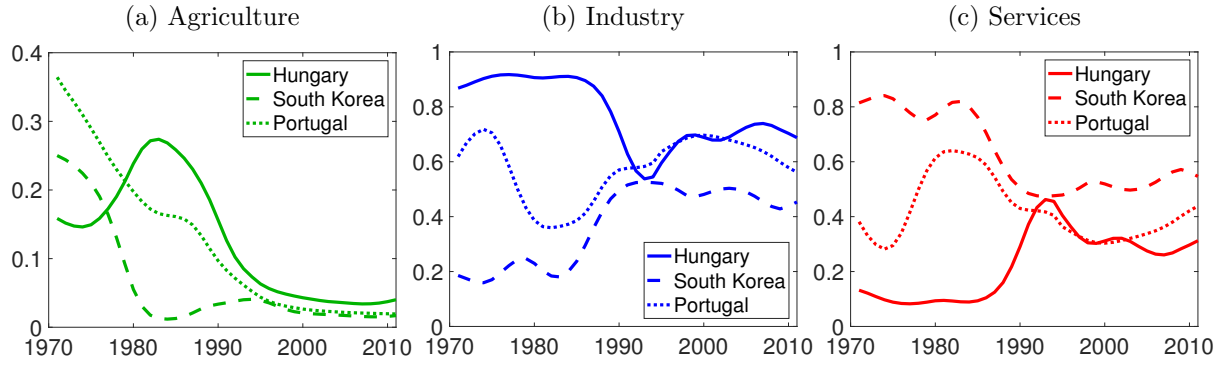


Notes: Vertical axes - Trade bilateral-trade-weighted- export barrier: $\sum_{j=1, j \neq i}^I d_{jit}^k \frac{Trd_{jit}^k}{Exp_{it}^k}$, over time, where Trd_{jit}^k is the value of sector k trade flows from country i to country j at time t and Exp_{it}^k is the value of country i sector k exports.

Preference shocks Figure 13 plots the preference shock level, ω_{it}^{Ck} , over time for each sector. The terms $\omega_{it}^{Cm} + \omega_{it}^{Cs} = 1, \forall(i, t)$ and these are normalized so that $\omega_{U1970}^{Cm} = \omega_{U1970}^{Cs} = 0.5$, where U denotes the United States. This normalization is free up to scaling of prices and does not affect any equilibrium allocations. There are two main takeaways from the plots of these shocks. First, from agriculture, it is clear that having the Stone-Geary part of preferences is not enough to capture the decline in the employment and value-added shares of agriculture. Rather, declining preference weights are needed, too. Second, for Hungary's industry sector, there was a big decline in its preference weight around 1990 that brought the weight closer to that of Portugal and South Korea. Prior to 1990, the industry preference weight in Hungary was significantly higher than that of the other two countries. This feature might reflect distortions in Hungary's economy that encouraged a greater consumption of industrial goods prior to 1990. After 1990, these distortions may have lifted and consumers expenditures shifted more toward services.

Labor wedges Figure 14 plots the gross labor wedge, $1 + \lambda_{it}^k$, over time for each sector. The labor wedge in industry is normalized to $\lambda_{it}^m = 1$ in every country and every year. Again, a wedge greater than one would be associated with a decrease in employment in the sector.

Figure 13: Sectoral preference shocks: 1970-2011

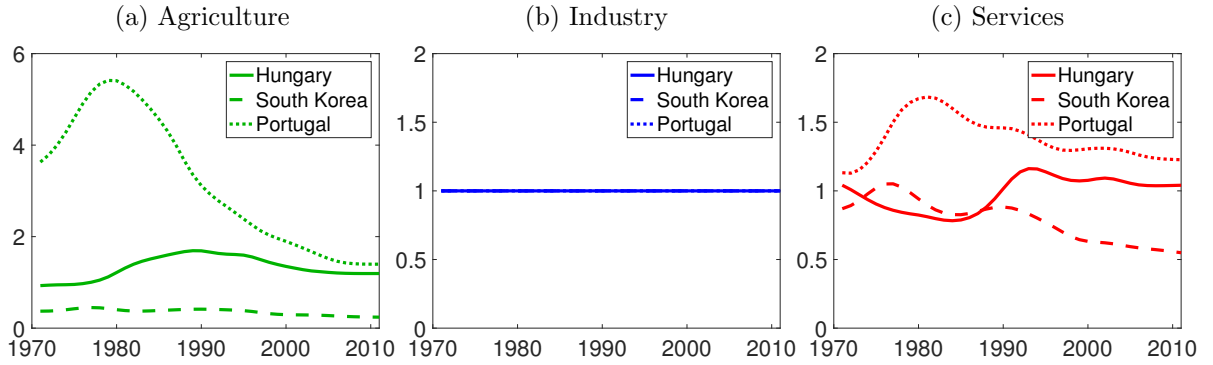


Notes: Vertical axes - Preference shock: ω_{it}^{Ck} . The terms $\omega_{it}^{Cm} + \omega_{it}^{Cs} = 1, \forall(i, t)$ and these are normalized so that $\omega_{U1970}^{Cm} = \omega_{U1970}^{Cs} = 0.5$, where U denotes the United States.

Focusing on the service sector graph, Hungary's labor wedge displayed a decline prior to 1990, then a sharp increase until about 1995, and then little change since then.

These wedges can have several interpretations. One interpretation is that, in Hungary, prior to 1990, workers in industry had a relatively higher marginal product than in services, perhaps because of a higher industrial policies aimed to heavy industry resulting in a concentration of capital in the industry sector. During the 1990s these marginal product of labor equalized quite a bit between industry and services.

Figure 14: Sectoral gross labor wedges: 1970-2011



Notes: Vertical axes - Gross labor wedge: $1 + \lambda_{it}^k$. The labor wedge in industry is normalized to $\lambda_{it}^m = 0$ in every country and every year.

Summarizing the four sets of wedges, we see that over time and with few exceptions,

Hungary’s wedges tend to converge to Portugal’s, especially after 1990. By contrast, with few exceptions, Korea’s wedges tended to be different both in levels and trends.

6 Structural accounting decompositions

The graphs of the four sets of wedges in the previous section are informative about the sizes, as well as the timing, of the changes in the wedges. They provide suggestive evidence on their relative importance in affecting the key variables like the sectoral employment shares. However, they do not provide a definitive assessment of how important each set of wedges is in accounting for Hungary’s industry share of employment, for example. In order to ascertain this importance, we need to conduct counterfactual simulations, which we call structural accounting decompositions, with our model. We do so in this section. For each set of wedges, we examine the effect of holding the wedges constant at their 1970 levels. We focus on accounting for the evolution of the industry employment share across the three countries; we also seek to account for the sharp increase in Hungary’s openness in the 1990s.

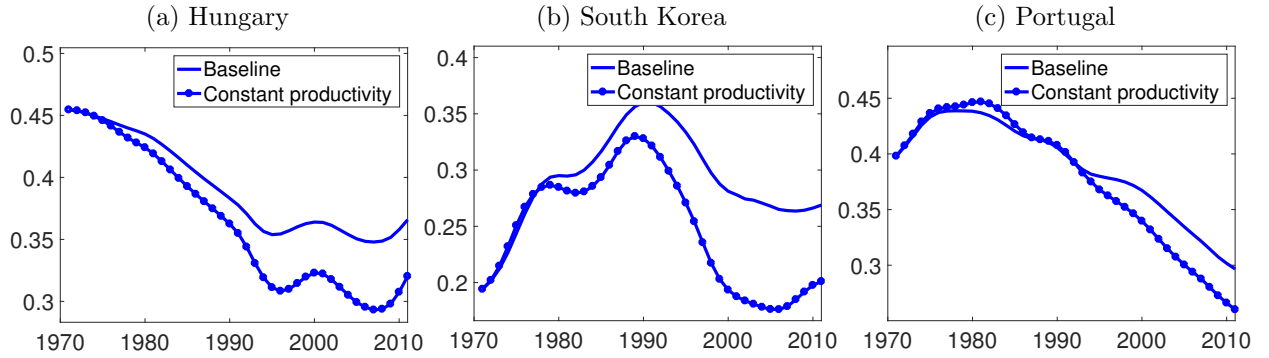
6.1 Hold country-level productivity constant

In the first exercise, we hold country i ’s productivity levels in all sectors constant at 1970 levels, $T_{it}^k = T_{i1970}^k, \forall (k, t)$, but allow productivity to vary over time in every other country $j \neq i$. (All the other wedges are varying over time, as well.) We do this for each of Hungary, South Korea, and Portugal. Figure 15 shows the industry employment share both in the baseline model—with all wedges varying over time—and in the counterfactual. In all three countries, the industry employment share is lower in the counterfactual than in the baseline for virtually all years.

This might not seem obvious—how could industry’s employment share be high if its productivity is growing—*ex ante*, but there are a couple of subtle issues here. First, the elasticity of substitution in preferences between industry and services is less than 1. This means, all else equal, that an increase in productivity in industry leads to a decrease in employment; hence, holding productivity constant, as in the counterfactual, should lead to an increase in employment, not a decrease. However, there are two offsetting forces. The first is that with zero productivity growth in industry, then, incomes are rising more slowly than otherwise, which implies that the desire to substitute away from agriculture-related products towards industry and services, taken together, is lower than otherwise. This could be one reason why the industry employment share in the counterfactual is lower than in the

baseline. In addition, to the extent that industry is where the country has a comparative advantage, then relatively high productivity growth can lead to higher employment, all else equal. When comparing sectoral productivity growth across countries, we see that Korea gained comparative advantage in industry, which led to a rise in their industry net exports and also contributed to their rise in industry production and employment. Eliminating that productivity growth will reduce employment, then. In our interpretation, these two offsetting forces dominate the first force.

Figure 15: Productivity held constant at 1970 level



Notes: Vertical axes are the industry employment shares.

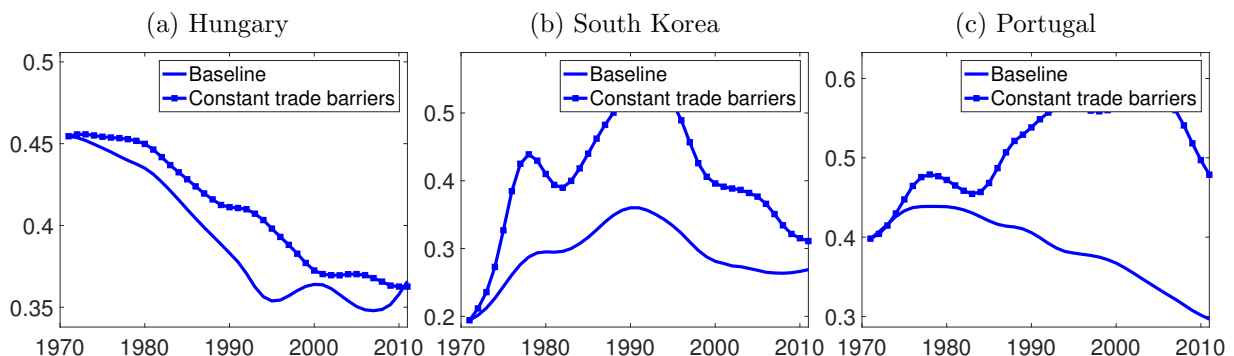
6.2 Hold country-level trade barriers constant

In this counterfactual, we hold each country's i 's trade barriers in all sectors constant at 1970 levels, $d_{i\ell t}^k = d_{i\ell 1970}^k$ and $d_{\ell i t}^k = d_{\ell i 1970}^k, \forall(\ell, k, t)$, but allow trade barriers to vary over time in every other country $j \neq i$. Figure 16 shows the industry employment share both in the baseline model—with all wedges fed into the model—and in the counterfactual. In all three countries, the industry employment share is higher in the counterfactual. This result also seems puzzling at first glance. Trade barriers, especially in industry, have broadly declined since 1970. How could a world that is more closed yield a result in which industry employment is higher than otherwise? Once again, the rationale is somewhat subtle and it differs across the three countries. The global decline in industry trade barriers contributed to a declining relative price of industry across most countries, thereby expediting the decline in the industry employment share and the rise in service's share. The declining barriers also contributed to rising income levels, also expediting the declining in industry and the rise in services.

At the country level, different rates of change in trade barriers across sectors affects a country's relative competitiveness on the global market and influence sectoral production and employment shares. Moreover, within a sector, a country's terms of trade depends on the behavior of import barriers relative to export barriers. In Hungary, for example, the gap between the baseline and the counterfactual expanded until about the mid-1990s, and then it narrowed after that. As figures 11b and 12b show, Hungary's industry import barrier declined and its export barrier rose in the period up until the mid-1990s. All else equal, this will tend to increase imports of industry goods, leading to a decline in industry employment. Hence, the absence of these changes in trade barriers would lead to an increase in industry employment, all else equal. For the period after the mid-1990s, the opposite holds – Hungary's industry export barrier declined, and its import barrier rose, so that all else equal, Hungary's industry employment share increased. Hence, for this period, not changing the barriers would mean a smaller difference between the baseline and counterfactual than otherwise.

Regarding South Korea, we view the story as somewhat different. If we examine Figures 11b and 12b, we see that South Korea's industry import barriers had a secular downward trend, while its industry export barriers had no such trend. Hence, the changes in trade barriers encouraged South Korea to import more and produce less industrial goods than otherwise. Holding those barriers constant would then lead South Korea to have more industrial production, and higher employment in industry than otherwise, as seen in 16b.

Figure 16: Trade barriers held constant at 1970 level



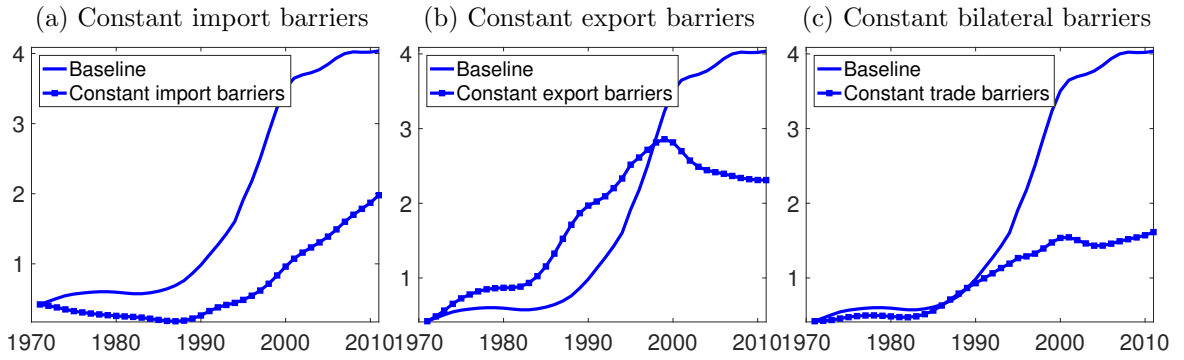
Notes: Vertical axes are the industry employment shares.

As figure 8b shows, Hungary experienced an enormous increase in its openness following 1990, no doubt owing to its transition to a market economy at that time. It is natural to think

that changes in their trade barriers contributed to this. We conduct two counterfactuals, one in which Hungary's import barriers are held constant, and one in which Hungary's export barriers are held constant, to ascertain the importance of each barrier.

Holding Hungary's import barriers constant leads to counterfactually low openness in industry – as of 2011, openness is about half that observed in the baseline (see Figure 17a). This patterns reflects the fact that Hungary's import barriers declined substantially prior to the 1990s so, by counterfactually holding these barriers constant at their 1970 level, imports and, hence, trade, counterfactually decrease relative to the baseline.

Figure 17: Hungary trade barriers held constant at 1970 level



Notes: Vertical axes are the trade openness in the industry sector.

Holding Hungary's export barriers, i.e., barriers that its exports face, constant leads to counterfactually high openness in industry prior to 2000, and counterfactually low openness after 2000 (see Figure 17b). This occurs because, relative to the initial year (1970), Hungary's calibrated export barrier is high prior to 2000. Therefore, Hungary's industry exports are more internationally competitive in the counterfactual, compared to the baseline, yielding greater openness. After 2000, Hungary's export barriers are lower than in 1970, so the counterfactual exports are lower than in the baseline, thus reducing openness.

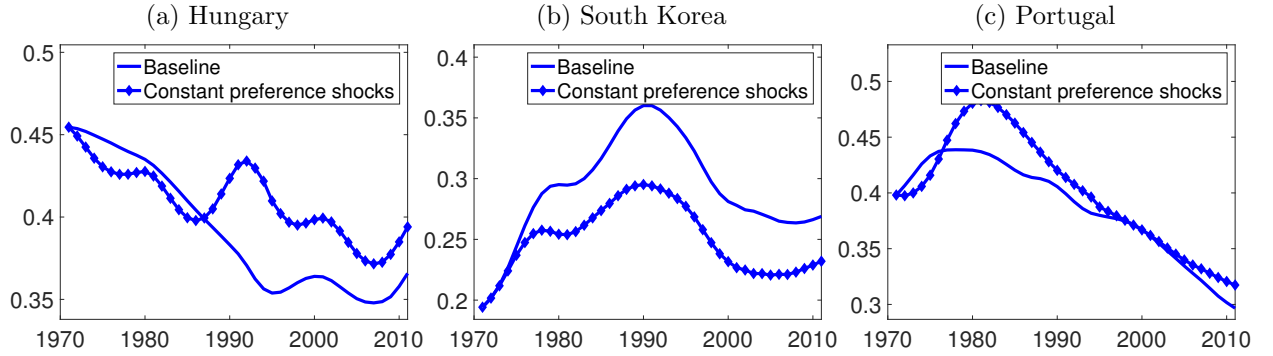
Figure 17c depicts Hungary's industry openness when holding both its import and export barriers constant. Prior to 1990, the counterfactual openness is similar to the baseline openness because the declining import barriers stimulate higher trade through greater imports, which offsets the falling exports and trade from greater export barriers. After 1990, Hungary's import barriers are roughly constant, while the export barriers decline sharply, inducing rising openness in the baseline compared to the counterfactual.

6.3 Hold country-level preferences constant

We now examine the effect of holding country i 's preference (weights) in all sectors constant at 1970 levels, $\omega_{it}^{Ck} = \omega_{i1970}^{Ck}, \forall(k, t)$, but allow preferences to vary over time in every other country $j \neq i$. Figure 18 shows the industry employment share both in the baseline model and in the counterfactual. For Hungary, following 1990, the counterfactual exhibits considerably higher industry employment than in the baseline. In South Korea, by contrast, the counterfactual industry employment share is considerably lower than in the baseline.

We attribute the result for Hungary to the sharp decline in its “preference” for industrial goods in 1990. Figure 18a shows that in the absence of the share decline in this preference, Hungary's industry employment share would have been about 2-5 percentage points higher. We think there is a rationale for this preference shock in Hungary; namely, that prior to the fall of the Berlin Wall, the planned economy called for greater industrial production than would occur in a market economy. The sudden transition to a market economy then, shows up in our framework partially as a decline in the preferences for industrial goods.

Figure 18: Preferences held constant at 1970 level



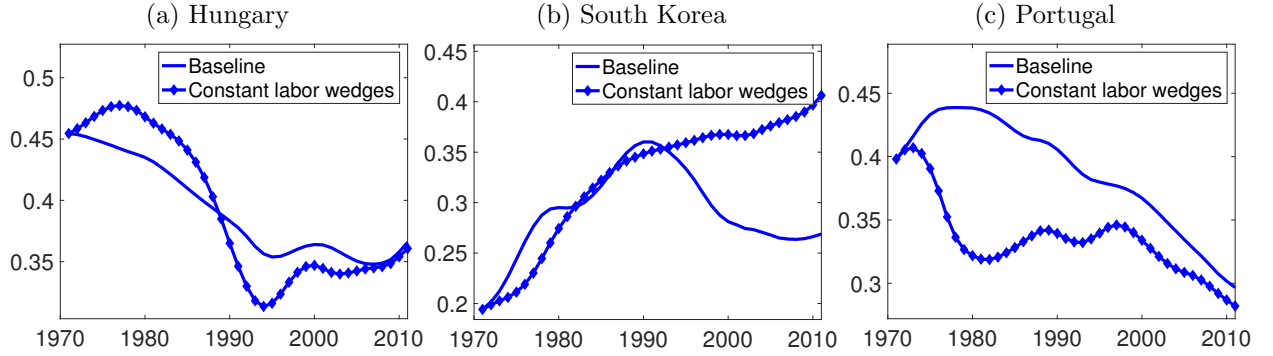
Notes: Vertical axes are the trade openness in the industry sector.

For South Korea, the story is virtually the opposite. Starting in the mid-1980s, South Korea experienced a sharp increase in its “preference” for industrial goods. This shows up in the baseline counterfactual as an increase in the industry sector employment share. Hence, in the absence of the increase in preferences for industrial goods, South Korea's industry employment share would be about five percentage points lower than otherwise.

6.4 Hold country-level labor wedges constant

In this set of counterfactuals, we hold one country i 's labor wedge shocks in all sectors constant at 1970 levels, $\lambda_{it}^k = \lambda_{i1970}^k, \forall(k, t)$, but allow labor wedges to vary over time in every other country $j \neq i$. Figure 19 shows the industry employment share both in the baseline model and in the counterfactual.

Figure 19: Labor wedges held constant at 1970 level



Notes: Vertical axes are the trade openness in the industry sector.

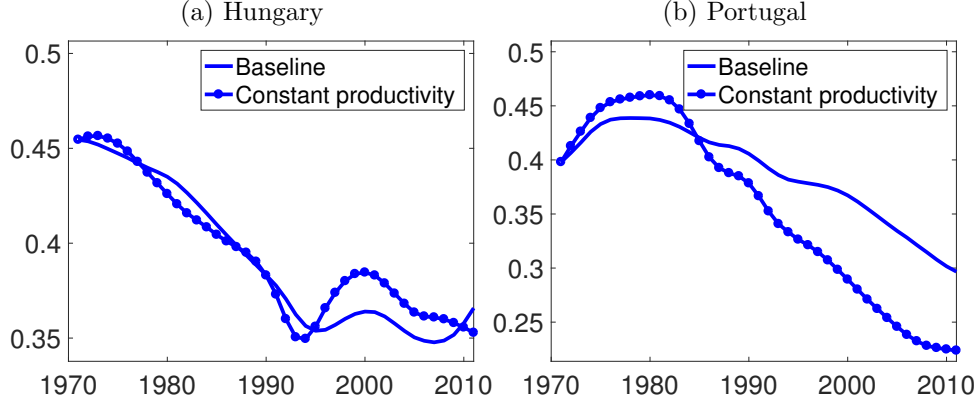
Our interpretation for Hungary involves the services labor wedge. This wedge declined from 1970 until the late 1980s, then increased over 10 years, before declining slowly after the mid-1990s. The fact that the agriculture labor wedge rose in the mid-1980s, implies less employment in agriculture, and higher employment in industry, than otherwise. Hence, in the counterfactual, there will be lower employment in industry than otherwise. The services labor wedge pattern implies more services employment in the 1970s through mid-1980s, less between the mid-1980s and mid-1990s, and more after the mid-1990s. In other words, there would be less employment in industry in the 1970s through 1980s, more industrial employment between the mid-1980s and mid-1990s, and less industrial employment after the mid-1990s – all in the baseline. Finally, with the labor wedges held constant, this would push industrial employment to be higher in the 1970s through 1980s, lower in the mid-1980s through mid-1990s, and higher after the mid-1990s, as seen in Figure 19a.

For South Korea, our interpretation is also based on the behavior of the services wedge, which declined following the early 1990s. In the baseline model, this implies higher services employment and lower industrial employment. Hence, in the absence of any change in the wedges, industrial employment would be higher than otherwise, as shown in Figure 19b.

6.5 Hold country-level production structure constant

This counterfactual assumes that country-level production structures are constant over time and fixed at 1970 levels. Specifically, this means that we hold the input-output coefficients and value added-to-gross output ratios constant in one country i only: $\mu_{it}^{k\ell} = \mu_{i1970}^{k\ell}$ and $\nu_{it}^k = \nu_{i1970}^k$. If we look back at the sectoral employment shares Figure 7, we can see that Hungary and Portugal had about the same industry employment shares in 2000, around 36 percent. Over the next decade, Hungary's employment share stayed roughly constant, while Portugal's declined by around seven percentage points. It turns out that evolving production structures in the two countries played a key role. As Figure 20b shows, when we hold Portugal's production structure constant, we find that Portugal's industry employment share would have declined by about five-and-one-half percentage points; when we hold Hungary's production structure constant, Hungary's share would have declined by about three percentage points. In other words, under constant production structures, the difference between the two countries' change in the industry employment share between 2000 and 2011 would have been only about two-and-one-half percentage points. Put differently, the evolving production structure over time accounts for about two-thirds of the widening gap in industry employment share between Portugal and Hungary.

Figure 20: Production structures held constant at 1970 level



Notes: Vertical axes are the trade openness in the industry sector.

When we take a closer look at what features of the production structure changed, we find that both the value-added to gross output ratio, as well as the importance of industry in overall intermediates usage, play a role. In Portugal, the value-added to gross output ratio, and the importance of industry in overall intermediates usage, declined relative to Hungary

in the decade following 2000.

7 Conclusion

To be added.

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A Data Sources

Our data draw from numerous sources including the WIOD, EU-KLEMS, Penn World Tables, GGDC 10-sector Database, and many other databases. To be added.

The list of countries in Figures 1 and 2, and used in the regression analysis include: The countries (isocodes) are: Australia (AUS), Austria (AUT), Belgium-Luxembourg (BLX), Brazil, (BRA), Bulgaria (BGR), Canada (CAN), China (CHN), Cyprus (CYP), Germany (DEU), Denmark (DNK), Spain (ESP), Finland (FIN), France (FRA), United Kingdom (GBR), Greece (GRC), Hungary (HUN), Indonesia (IDN), India (IND), Ireland (IRL), Italy (ITA), Japan (JPN), South Korea (KOR), Mexico (MEX), Netherlands (NLD), Poland (POL), Portugal (PRT), Sweden (SWE), Switzerland (CHE), Turkey (TUR), Taiwan (TWN), United States (USA), Argentina (ARG), Malaysia (MYS), Mauritius (MUS), Morocco (MAR), Philippines (PHL), Singapore (SGP), South Africa (ZAF), Thailand (THA), and the Rest-of-world (ROW).

For the regression analysis, the countries are grouped as follows: Eastern Europe (10): Bulgaria, Czech Republic, Estonia, Hungary, Lithuania, Latvia, Poland, Romania, Slovakia, and Slovenia. Southern Europe (6): Cyprus, Spain, Greece, Italy, Malta, and Portugal. Northern Europe (11): Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, Netherlands, Sweden, and United Kingdom. Other advanced (6): Australia, Canada, Japan, South Korea, Taiwan, United States Emerging (7): Brazil, China, Indonesia, India, Mexico, Russia, Turkey

For the quantitative analysis (Sections 5 and 6), we use 28 countries/regions: Australia (AUS), Austria (AUT), Belgium-Luxembourg (BLX), Brazil, (BRA), Canada (CAN), China (CHN), Cyprus (CYP), Germany (DEU), Denmark (DNK), Spain (ESP), Finland (FIN), France (FRA), United Kingdom (GBR), Greece (GRC), Hungary (HUN), Indonesia (IDN), India (IND), Ireland (IRL), Italy (ITA), Japan (JPN), South Korea (KOR), Mexico (MEX), Malta (MLT), Netherlands (NLD), Portugal (PRT), Sweden (SWE), Turkey (TUR), Taiwan (TWN), United States (USA), and the Rest-of-world (ROW).

B Solving the equilibrium

Table B.1 provides a set of equations that characterize the equilibrium of the economy.

Table B.1: Equilibrium conditions

(S1)	$r_{it}K_{it}^k = \alpha\nu_{it}^k P_{it}^k Y_{it}^k$	$\forall(k, i, t)$
(S2)	$(1 + \lambda_{it}^k)w_{it}L_{it} = (1 - \alpha)\nu_{it}^k P_{it}^k Y_{it}^k$	$\forall(k, i, t)$
(S3)	$P_{it}^\ell M_{it}^{k\ell} = (1 - \nu_{it}^k)\mu_{it}^{k\ell} P_{it}^k Y_{it}^k$	$\forall(k, \ell, i, t)$
(S4)	$P_{it}^k = \gamma^k \left(\sum_{j=1}^I \left((T_{jt}^k)^{-\nu_{jt}^k} u_{jt}^k d_{ijt}^k \right)^{-\theta^k} \right)^{-\frac{1}{\theta^k}}$	$\forall(k, i, t)$
(S5)	$\pi_{ijt}^k = \frac{\left((T_{jt}^k)^{-\nu_{jt}^k} u_{jt}^k d_{ijt}^k \right)^{-\theta^k}}{\sum_{h=1}^I \left((T_{ht}^k)^{-\nu_{ht}^k} u_{ht}^k d_{iht}^k \right)^{-\theta^k}}$	$\forall(k, i, t)$
(D1)	$P_{it}^a C_{it}^a = \omega_{it}^{C^a} (P_{it}^C C_{it} - L_{it} P_{it}^a \bar{c}^a) + L_{it} P_{it}^a \bar{c}^a$	$\forall(i, t)$
(D2)	$P_{it}^k C_{it}^k = \omega_{it}^{C^k} \left(\frac{P_{it}^k}{P_{it}^N} \right)^{1-\sigma} \left(\frac{C_{it}^N}{L_{it}} \right)^{\varepsilon^k - 1}$	$\forall(i, t) \text{ \& } k \in \{m, s\}$
(D3)	$P_{it}^N C_{it}^N = (1 - \omega_{it}^{C^a}) (P_{it}^C C_{it} - L_{it} P_{it}^a \bar{c}^a)$	$\forall(i, t)$
(D4)	$P_{it}^N = \left(\sum_{k \in \{a, m, s\}} (\omega_{it}^{C^k})^\sigma \left(\frac{C_{it}^N}{L_{it}} \right)^{\varepsilon^k - 1} (P_{it}^k)^{1-\sigma} \right)^{\frac{1}{1-\sigma}}$	$\forall(i, t)$
(D5)	$P_{it}^C = \left(\frac{P_{it}^a}{\omega_{it}^{C^a}} \right)^{\omega_{it}^{C^a}} \left(\frac{P_{it}^N}{1 - \omega_{it}^{C^a}} \right)^{1 - \omega_{it}^{C^a}}$	$\forall(i, t)$
(D6)	$P_{it}^k X_{it}^k = \omega_{it}^{X^k} P_{it}^X X_{it}$	$\forall(i, t)$
(D7)	$X_{it} = \prod_{k \in \{a, m, s\}} (X_{it}^k)^{\omega_{it}^{X^a}}$	$\forall(i, t)$
(D8)	$P_{it}^X = \prod_{k \in \{a, m, s\}} \left(\frac{P_{it}^k}{\omega_{it}^{X^k}} \right)^{\omega_{it}^{X^a}}$	$\forall(i, t)$
(D9)	$P_{it}^X X_{it} = \rho_{it} (w_{it} L_{it} + r_{it} K_{it} + R_{it}^G)$	$\forall(i, t)$
(D10)	$K_{it+1} = (1 - \delta) K_{it} + X_{it}$	$\forall(i, t)$
(D11)	$P_{it}^C C_{it} + L_{it} P_{it}^a \bar{c}^a + P_{it}^X X_{it} = (1 - \phi_{it}) (w_{it} L_{it} + r_{it} K_{it} + R_{it}^G) + R_{it}^P L_{it}$	$\forall(i, t)$
(M1)	$K_{it} = \sum_{k \in \{a, m, s\}} K_{it}^k$	$\forall(i, t)$
(M2)	$L_{it} = \sum_{k \in \{a, m, s\}} L_{it}^k$	$\forall(i, t)$
(M3)	$Q_{it}^k = C_{it}^k + X_{it}^k + \sum_{\ell \in \{a, m, s\}} M_{it}^{k\ell}$	$\forall(k, i, t)$
(M4)	$R_{it}^G = w_{it} \sum_{k \in \{a, m, s\}} \lambda_{it}^k L_{it}^k$	$\forall(i, t)$
(M5)	$\sum_{i=1}^I L_{it} R_{it}^P = \sum_{i=1}^I \phi_{it} (w_{it} L_{it} + r_{it} K_{it} + R_{it}^G)$	$\forall(t)$

Notes: $u_{jt}^k = \left(\frac{r_{jt}}{\alpha \nu_{jt}^k} \right)^{\alpha \nu_{jt}^k} \left(\frac{(1 + \lambda_{jt}^k) w_{jt}}{(1 - \alpha) \nu_{jt}^k} \right)^{(1 - \alpha) \nu_{jt}^k} \left(\prod_{\ell \in \{a, m, s\}} \left(\frac{P_{jt}^\ell}{\mu_{jt}^{k\ell}} \right)^{\mu_{jt}^{k\ell}} \right)^{1 - \nu_{jt}^k}$.