Evolving Comparative Advantage, Sectoral Linkages, and Structural Change

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Abstract

I quantitatively examine the effects of location- and sector-specific productivity growth on structural change across countries from 1970-2011. The results shed new light on the "hump shape" in industry's share in GDP across levels of development. There are two key features. First, otherwise identical changes in the composition of final demand translate differently into changes in the composition of value added because of systematic differences in sectoral linkages. Second, the mapping between sector-specific productivity and the composition of final demand systematically differs because of the relative importance of two components within final demand: final domestic expenditures and net exports.

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1 Introduction

Historically, the process of economic development has been accompanied by massive shifts in the composition of economic activity. Beginning with Kuznets (1973), an extensively documented fact has been the movement in economic activity from agriculture into industry and then from industry into services. At any point in time, countries differ markedly in terms of their compositions of economic activity, yet, the composition in each country is closely linked to its level of development. One aspect that has garnered recent attention is the "hump shape" in industry's share in economic activity: the rise in industry's share at lower levels of development and the decline at higher levels of development (see Buera and Kaboski, 2012; Uy, Yi, and Zhang, 2013; Herrendorf, Rogerson, and Valentinyi, 2014).

The goal of this paper is two-fold. First, to utilize a benchmark model, with well-understood features, as a tool to measure sectoral productivity across heterogeneous countries from 1970-2011. Second, to use the model as a laboratory to systematically evaluate the quantitative magnitude through which location- and sector-specific productivity growth impacted the observed compositions of value added throughout time. In doing so, I highlight key differences between advanced and emerging economies that shed light on the hump shape in industry's share in value added across levels of development.

Relative to the existing literature, I systematically evaluate how sector-specific productivity growth maps into structural change across both emerging Asian economies and advanced economies, simultaneously, in a general equilibrium framework. I find that the mapping systematically differs between emerging Asian economies and advanced economies for two reasons. First, given otherwise similar changes to the composition of final demand across countries, the composition of value added responds differently across countries because of differences in input-output linkages. Second, the composition of final demand responds differently to innovations in sectoral productivity because the relative importance of two components within final demand: final domestic expenditures and net exports. In addition, I disentangle the quantitative effects of domestic versus foreign productivity growth on structural change.

The main results are the following. First, emerging Asian economies utilize industrial goods more intensively than advanced economies in the production of services. Therefore, given otherwise similar increases in service's share in final demand, emerging Asian economies would have experienced a relatively larger increase in derived demand for industrial goods production and a larger increase in industry's share in value added, relative to advanced economies.

Second, in emerging Asian economies, the net export channel is relatively stronger than the final domestic expenditure channel, compared to advanced economies, since the foreign market is large compared to the domestic market. Consequently, increased efficiency in industrial production in emerging Asian economies initiated an improvement in comparative advantage that required more resources to satisfy increased net exports. Conversely, in advanced economies the final domestic expenditure channel is relatively stronger than the net export channel, compared to emerging Asian economies, since the domestic market is large compared to the foreign market. Therefore, domestic prices and, hence, final domestic expenditures have a strong response to changes in domestic productivity. As a result, increased efficiency in industrial production in advanced economies required fewer resources to produce similar levels of output and resources shifted out of industry.

Third, income effects played a substantial role in emerging Asian economies, intensifying the rate at which agriculture's share in value added declined and industry's share increased. In advanced economies, income effects were nearly inconsequential.

Understanding the various channels through which sector-specific productivity growth affects structural change is important for at least two reasons. First, from macro-development standpoint, cross-country differences in the composition of economic activity are important to understand differences in aggregate economic outcomes (see Duarte and Restuccia, 2010; Gollin, Lagakos, and Waugh, 2014). Simple arithmetic implies that aggregate productivity is an average of the productivities in each sector, weighted by each sector's share in the aggregate. As a corollary the aggregate growth rate of an economy boils down to the average of the sector-specific productivity growth rates weighted by the evolution of the sectoral shares. McMillan and Rodrik (2011) argue that reallocations of resources across sectors has been growth reducing for some countries and growth enhancing for others, depending on whether resources shifted towards sectors with relatively lower or higher productivity. Recent research has found that differential productivity growth across sectors itself is, quantitatively, a key determinant of structural change (see Uy, Yi, and Zhang, 2013; Herrendorf, Herrington, and Valentinyi, 2014; Świecki, 2014). Therefore, whether an improvement in a sector's productivity actually increases GDP per capita or not very much depends on how the composition of resources changes in response.

Second, the decline in industry's share in value added in advanced economies has spurred social and political debates regarding increased protection based on the concern that manufacturing jobs are moving abroad to emerging Asian economies where industry's share has increased. Meanwhile, technological advancements in manufacturing processes via automation provide an additional explanation for the decline in industry's share in employment and, hence, value added.

I construct a three-sector, multi-country, model of structural change with Ricardian incentives for trade. Agricultural and industrial goods are tradable while services are not. The model draws on four important mechanisms. The first is income effects due to Ernst Engel. As countries grow agriculture accounts for a declining share of final domestic expenditures and, hence, a smaller share of aggregate value added. I model this channel by imposing an income elasticity of agricultural consumption less than 1. Examples of this mechanism in closed economies can be found in Kongsamut, Rebelo, and Xie (2001) and Laitner (2000). In a small open economy, Teignier (2012) shows that trade speeds up the decline in agriculture's share by allowing developing economies to import agriculture from more productive sources.

The second mechanism is due to Baumol (1967)—known as the Baumol effect—which has been popularized by Ngai and Pissarides (2007). In each country productivity growth differs across sectors leading to changes in relative prices over time. Consumers view the goods and complementary and allocate an increasing share of final domestic expenditures towards the goods with an increasing relative price, or slowest productivity growth. That is, resources shift toward the sector with the slowest growing productivity.

The third mechanism is changes in comparative advantage via international trade as in Uy, Yi, and Zhang (2013). There is a continuum of varieties in each sector that can be traded. Each country's efficiency for producing each variety is the realization from a country- and sector-specific distribution à la Eaton and Kortum (2002). The scale parameter of the distribution determines a country's average productivity in a given sector. Asymmetric productivity growth, both across sectors and across countries, generates changes in comparative advantage. Countries that experience an increase in comparative advantage in a given sector will allocate an increasing share of resources towards that sector to satisfy net exports. The fact that this mechanism works in the opposite direction of the Baumol effect is emphasized by Matsuyama (2009) as a reason to study structural change in an open economy.

The fourth mechanism is sectoral linkages on the production side of the economy. As in Caliendo and Parro (2014) and Caliendo, Parro, Rossi-Hansberg, and Sarte (2014), I explicitly model location-specific input-output structures. In the absence of an input-output structure, changes in the composition of value added are isomorphic to changes in the composition of final demand (final domestic expenditures plus net exports). In the presence of sectoral linkages, an increase in final demand for, say, services, stimulates an increased demand for inputs from all sectors. The coefficients of the input-output structure determine the extent of the derived demand from each sector. I show that differences in the coefficients in the input-output matrix between advanced and emerging Asian economies helps explain part of the rise in industry's share in value added in emerging Asian economies relative to advanced economies.

Limited data on inputs in production poses a challenge to measure productivity at the sectoral level across many countries and over time. Instead, researchers often infer productivity through the lens of a model by exploiting more readily available data. For instance, Levchenko and Zhang (2012) estimate sector-specific productivity across 75 countries and throughout time using a gravity-based framework by exploiting data on production and trade flows for 19 manufacturing sectors. Due to the limited availability of data on trade in services, I cannot apply the same method to estimate productivity in the services sector.

Alternatively, I employ a highly tractable method, similar to Święcki (2014), to measure productivity for all sectors including services. I pick the country- and sector-specific productivities to match the observed composition of value added and the GDP per capita in each country throughout time.

I discipline the trade barriers in the model by matching the data on bilateral trade shares in agriculture and industry. Since the model matches the targets almost perfectly, I use the model as a laboratory to conduct a series of counterfactual exercises to quantify the extent to which productivity growth impacted structural change.

There is a growing literature on structural change in general, but also more specifically on structural change in open economy settings. Uy, Yi, and Zhang (2013) show both theoretically and empirically, in a two-country environment, that the combination of the Baumol effect and changes in comparative advantage can help explain the hump shape in the share of manufacturing employment in South Korea from 1971-2005. Their key insight is that the fast productivity growth in Korea's manufacturing sector led to a growing comparative advantage in that sector, which explains the rising portion of the hump shape of the manufacturing sector. The flattening of manufacturing's share is a result of the domestic expenditures shifting towards the service sector as Korea became more developed. That is, in early years the net export channel dominates the final domestic expenditure channel and vice versa in later years. Betts, Giri, and Verma (2013) also study structural change in South Korea and argue that the trade reforms of the 1960s played a quantitatively important role in the rise of manufacturing's share in employment.

Both of the aforementioned papers reveal the importance of considering trade linkages in explaining Korea's structural transformation. While they utilize two-country models and examine the implications for only one country, I add to these works by systematically evaluating structural change across multiple countries simultaneously. In addition, I explore the importance of differences in sectoral linkages across countries. My findings imply that closed-economy models can be misguided for thinking about structural change in emerging Asian economies in general.

Świecki (2014) studies structural change across a large number of countries to identify what features are quantitatively the most relevant, i.e. asymmetric productivity growth, non-homothetic preferences, trade and labor market wedges. He finds that asymmetric productivity growth is the most important factor in determining structural change across countries. My paper builds on Świecki (2014) along four dimensions. i) by examining the effect of productivity growth in each sector individually on structural change, ii) by individually isolating the importance of domestic versus foreign productivity growth on structural change in each country, iii) how the mapping between sectoral productivity growth and structural change systematically differs between advanced and emerging Asian economies and iv) by embedding sectoral linkages via country-specific input-output structures and quantifying their importance in understanding structural change.

Comin, Lashkari, and Mestieri (2015) also examine structural change across a large number countries and, in doing so, they disentangle the relative importance of price effects from income effects in explaining structural change along a balanced growth path. Their analysis is done in the context of a closed economy with no sectoral linkages.

In terms of methodology, my paper also relates to Caliendo, Parro, Rossi-Hansberg, and Sarte (2014). They examine how sectoral shocks that originate in individual U.S. states propagate throughout the U.S., by emphasizing both the trade linkages between states as well as the sectoral linkages in production.

Most of the literature on structural change focuses on the composition of employment. I focus on the composition of value added to allow for greater country coverage.

2 Empirical facts

In this section I document the process of structural change in a panel of 108 countries from 1970-2011. I also document systematic differences in sectoral linkages across countries at different levels of development.

Figure 1 plots the the composition of value added against economic development for the entire panel; each point denotes one country in one year. I measure the composition of value added using data in current prices. I measure economic development using expenditure-side real GDP per capita at chained PPPs (GDP per capita from now on). Buera and Kaboski (2012) show a similar pattern using historical data back to the 1800's for 30 countries, while Herrendorf, Rogerson, and Valentinyi (2014) do so for 10 currently developed countries.

I fit a trend line through each sector by regressing each sector's share in value added against a third-degree polynomial in the log of GDP per capita as follows:

$$v_{bit} = \beta_0 + \beta_1 y_{it} + \beta_2 y_{it}^2 + \beta_3 y_{it}^3 + u_{it} \qquad (1)$$

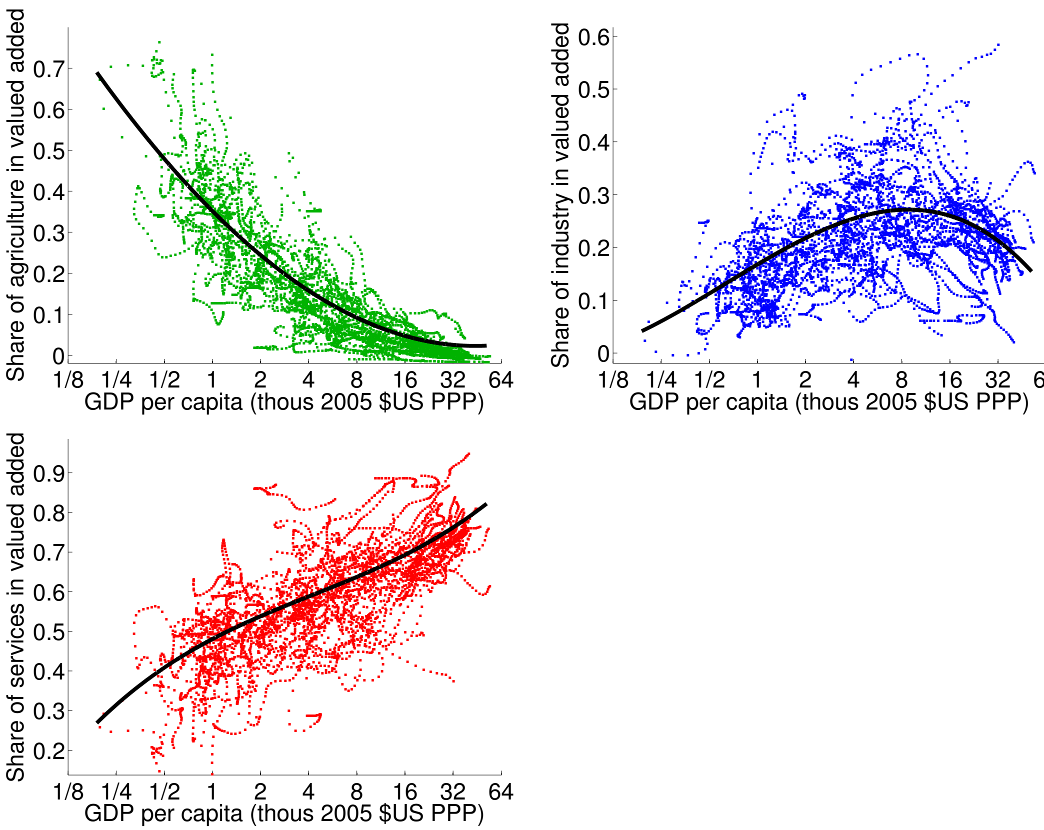
where y_{it} denotes the log of GDP per capita in country i at time t and v_{bit} denotes sector b's share in value added for $b \in \{a, m, s\}$ (agriculture, industry, services). There is a very strong negative relationship between agriculture's share and the level of development: the R^2 is 0.76. There is a positive relationship between the share of services and the level of development: the R^2 is 0.51. The share of industry exhibits a hump-shaped relationship with development: it is first increasing with development and then it is decreasing: the R^2 is 0.24.

Another way to view the relationship is by regressing logged GDP per capita against the composition of value added for the entire panel. Consider the following linear specification

$$y_{it} = \alpha + \beta_a v_{ait} + \beta_s v_{sit} + \epsilon_{it} \qquad (2)$$

For the entire panel of 108 countries from 1970-2011, the OLS estimate yields

Figure 1: Composition of value added against GDP per capita.



Note: The data covers 108 countries from 1970-2011. Each point denotes a sector's share in a country's value added in one year. The trend line is constructed by regressing the share of value added against a third-degree polynomial in the log of GDP per capita with a constant included. Value added is measured using current prices and GDP per capita is measured using expenditure-side real GDP at chained PPPs.

$\hat{\beta}_a = -6.20$ and $\hat{\beta}_s = 0.86$, each significant at the 95% level, with an $R^2 = 0.72$.

While the composition of value added appears to be systematically related to the level of development, there is a lot of variation that is unexplained. In particular, agriculture's share in value added is closely tied to the level of development throughout the entire panel, yet, there is quite a bit of variation in service's share—even more so in industry's share—that is not systematically related to the level of development. To capture the unexplained variation in each country, I estimate the dynamic relationship between the composition of value added and the level of development in each country using the following specification:

$$y_t^i = \alpha^i + \beta_a^i v_{at}^i + \beta_s^i v_{st}^i + \epsilon_t^i \tag{3}$$

I estimate equation (3) for each country individually using time series data. I use the coefficient of determination (CoD from now on) from each regression as a metric to gauge the strength of the dynamic relationship between the level of development and the composition of value added. African and Latin American countries tend to have low CoDs, while advanced economies and emerging Asian economies tend to have high CoDs. For instance, the CoD in the U.S. is 0.99 and is 0.96 in South Korea, while the CoD in both Venezuela and Guinea-Bissau is 0.03. Many African countries have yet to industrialize. Moreover, some Latin American countries, such as Brazil, instituted import substitution policies, while others, such as Argentina, experienced slow economic growth and have had relatively flat industrial shares in value added. I utilize this information to discipline the process of assigning countries into various groups in the quantitative analysis.

Input-output linkages across countries The next set of facts show how the input-output structure systematically differs across income levels, using data from the World Input-Output Database (WIOD). I utilize 31 countries from 1995-2011, although I report results only for the cross-section in 1995; the results for the other years are very similar.

Let r_{bni} denote sector n's share in intermediate spending by sector b, in country i. I estimate the intensity that each share varies across levels of development by regressing the share against the logarithm of GDP per capita: $r_{bni} = \alpha + \rho y_i + \varepsilon_i$. The point estimates of ρ_{bn}, along with the standard errors, are reported in Table 1. Among all the estimates, the most significant and striking are ρ_{sm} and ρ_{ss}. Poor countries tend to utilize industrial goods more intensively than rich countries do in the production of services. Rich countries, instead, utilize services inputs more intensively. These facts are reflected by

$\rho_{sm} < 0$ and $\rho_{ss} > 0$.[1]

Table 1: Estimates of the systematic variation in sectoral linkages

	ρ_{aa}	ρ_{am}	ρ_{as}	ρ_{ma}	ρ_{mm}	ρ_{ms}	ρ_{sa}	ρ_{sm}	ρ_{ss}
Slope	-0.006	-0.008	0.014	-0.009	-0.005	0.014	-0.002	-0.038	0.040
Std err	0.021	0.015	0.012	0.005	0.011	0.009	0.002	0.013	0.014

Note: I estimate systematic variation of the shares across 31 countries in 1995 as the slope of the following least-squares regression: $r_i = \alpha + \rho y_i + \varepsilon_{it}$, where r_i is the share under question in country i and y_i is the log of GDP per capita. ρ_{bn} denotes the estimate for the sector n's share in intermediate spending by sector b.

To examine the robustness of this fact, I measure the share of industrial goods as a fraction of total intermediate inputs across 17 service subsectors and 31 countries in 1995 (the estimates in years 1996-2011 are similar). I compute the intensity of each share with respect to GDP per capita as the slope coefficient from the following linear specification: $q_{ni} = \alpha + \chi_n y_i$, where q_{ni} is industry's share in total intermediate spending in subsector n in country i, and y_i is the logarithm of GDP per capita. In 15 of the 17 subsectors, the coefficient, χ_n, is negative and is significant at the 95 percent level in 4 of the subsectors. That is, for most of the service subsectors, poor countries tend to utilize industrial goods more intensively as inputs. In the two subsectors that the coefficient is positive, it is not statistically significant.

One sector that the differences stands out is in construction. In particular, the coefficient for the construction sector is negative and large. In addition, construction accounts for a larger share of output in emerging Asian economies than in advanced economies, thereby impacting the aggregate share of industry in services as a whole via a composition effect.

Summary of the facts There is a clear systematic relationship between the level of development and the composition of value added across a large set of countries over time. However, even controlling for levels of development, there is a lot of variation in compositions that remains to be explained. Countries differ in their import and export intensities, in their trade balances both

[1] Note that $\sum_n r_{bn} = 1$ by definition for each b. It follows that $\sum_n \rho_{bn} = 0$ for each b.

at the sectoral and aggregate level and in their composition of final domestic expenditures. Other potentially important factors include differences in institutional arrangements and in policies that distort the allocation of resources.

In the quantitative exercises in the paper, I aggregate individual countries into three groups: advanced economies (ADV), emerging Asian economies (EMA) and the rest of the world (ROW). This eliminates a lot of the idiosyncratic noise at the country level due to country-specific factors that are not of first order interest in this paper. Using this aggregation allows me to isolate four distinct features that are central to the analysis. First, both ADV and EMA contain countries that exhibit a strong dynamic relationship between economic development and the composition of value added. The average estimated CoD from equation (3) for countries in ADV is 0.96, is 0.96 for countries in EMA and is 0.66 for countries in ROW. Second, countries in EMA are on the opposite end of the income distribution compared to countries in ADV. Countries in ROW are mostly low-to-middle income. Third, each country in EMA experienced an increase in industry's share in value added from 1970-2011, while each country in ADV experienced a decrease. Therefore, the panel of three aggregated country groups exhibit a hump shape in industry's share across levels of GDP per capita as in Figure 1. Fourth, advanced economies exhibit a significantly different input-output structure than emerging Asian economies.

3 Model

I develop a three-sector, multi-country, Ricardian model of trade as in Uy, Yi, and Zhang (2013) and Święcki (2014). There are I countries indexed by $i = 1, \ldots, I$. Time is discrete and runs from $t = 1, 2, \ldots, T$. There are three sectors: agriculture, industry and services, denoted by a, m and s respectively. Within each sector there is a continuum of potentially tradable *varieties*. Production of each variety is carried out by competitive firms using labor and intermediates from all three sectors. As in Eaton and Kortum (2002), each country's efficiency in producing each variety is the realization of a random draw from a country- and sector-specific distribution. Trade is subject to iceberg costs. Each country purchases each variety from its least cost supplier and all of the varieties are combined into sector-specific *composite* goods. Composite goods are consumed by a representative household and used as intermediate inputs in production.

For purposes of presentation, I treat services as tradable. In the quantitative section of the paper I make services nontradable by setting trade barriers sufficiently high. In what follows I omit country and time subscripts where it is clear.

3.1 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.

3.2 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

$$Q_{bi} = \left[\int q_{bi}(x_b)^{1-1/\eta} dx_b \right]^{\eta/(\eta-1)}$$

where η is the elasticity of substitution between any two varieties.[2] The term $q_{bi}(x_b)$ is the quantity of good x_b used by country i to construct the sector b composite good. The resulting composite good, Q_{bi}, is the quantity of sector b composite good available in country i to use either as an intermediate input or for final consumption.

[2]The value η plays no quantitative role other than satisfying technical conditions which ensure convergence of the integrals.

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

$$y_{bi}(x_b) = z_{bi}(x_b) L_{bi}(x_b)^{\nu_{bi}} \left(\prod_{n \in \{a,m,s\}} M_{bni}(x_b)^{\mu_{bni}} \right)^{1-\nu_{bi}}$$

The term $M_{bni}(x_b)$, for $n, b \in \{a, m, s\}$, denotes the quantity of the composite good of type n used by country i as an input to produce variety x_b and $L_{bi}(x_b)$ denotes the quantity of labor employed.

The parameter $\nu_{bi} \in [0, 1]$, for $b \in \{a, m, s\}$, denotes the share of value added in total output in sector b, while $\mu_{bni} \in [0, 1]$ denotes the share of the good n in total spending on intermediates by producers in sector b, with $\sum_n \mu_{bni} = 1$. Each of these coefficients is country-specific and constant over time.

The term $z_{bi}(x_b)$ denotes country i's productivity for producing variety x_b. Following Eaton and Kortum (2002), the productivity draws come from independent country-, sector- and time-specific Fréchet distributions with sector-specific shape parameters θ_b for $b \in \{a, m, s\}$ and sector-, country- and time specific scale parameters T_{bit}, for $b \in \{a, m, s\}$, $i = 1, 2, \ldots, I$ and $t = 1, 2, \ldots, T$. The c.d.f. for productivity draws in sector b in country i at time t is $F_{bit}(z) = \exp(-T_{bit} z^{-\theta_b})$. Once the vector of cost draws is known, the actual index of the variety becomes irrelevant. So from now on each variety in sector b is denoted by its vector of productivity draws $z_{bt} = (z_{b1t}, z_{b2t}, \ldots, z_{bIt})'$ as in Alvarez and Lucas (2007).

Within each sector, the expected value of productivity across the continuum is $\gamma_b^{-1} T_{bi}^{1/\theta_b}$, where $\gamma_b = \Gamma(1+\frac{1}{\theta_b}(1-\eta))^{\frac{1}{1-\eta}}$ and $\Gamma(\cdot)$ is the gamma function. As in Finicelli, Pagano, and Sbracia (2012), I refer to T_{bi}^{1/θ_b} as the fundamental productivity in sector b in country i.[3] If $T_{ai} > T_{aj}$, then on average, country

[3] As discussed in Finicelli, Pagano, and Sbracia (2012), fundamental productivity differs from measured productivity because of selection. In a closed economy, country i produces all varieties in the continuum so its measured productivity is equal to its fundamental productivity. In an open economy, country i produces only the varieties in the continuum

i is more efficient than country j at producing agricultural goods. Average productivity at the sectoral level determines specialization across sectors. A country that has a large value of T_a, relative to the other sectors, will tend to be a net exporter in agriculture. The parameter $\theta_b > 0$ governs the coefficient of variation of the efficiency draws. A larger θ_b implies more variation in efficiency across countries in sector b and, hence, more room for specialization within each sector; i.e., more intra-sectoral trade.

3.3 Preferences

The representative household values consumption at each point in time according to

$$C_{it} = \left(\omega_a (C_{ait} - L_{it}\bar{c}_a)^{1-1/\varepsilon} + \omega_m C_{mit}^{1-1/\varepsilon} + \omega_s C_{sit}^{1-1/\varepsilon}\right)^{\varepsilon/(\varepsilon-1)}$$

where $\bar{c}_a$ denotes the minimum required level of consumption, per capita, of the agricultural good. The parameters $\omega_b \in [0,1]$ determine the relative importance of the sector b good in aggregate consumption. The term $\varepsilon > 0$ is the elasticity of substitution between the three goods. Each parameter is constant across countries and over time. I refer to C_{it} as aggregate discretionary consumption.

3.4 Foreign asset positions

I shut down the dynamic aspect of the household's decision problem by imposing an exogenous net-foreign asset position. This assumption implies that the household faces a sequence of static problems, yet still allows the model to match the data on aggregate trade imbalances. The representative household in country i lends a net value of ζ_{it} to foreign countries in period t. If $\zeta_{it} > 0$ then country i is a net lender at time t, otherwise it is a net borrower. At the world level, $\sum_i \zeta_{it} = 0$.

for which it has a comparative advantage and imports the rest. So its measured productivity is higher than its fundamental productivity, conditioning on the varieties that it produces in equilibrium.

3.5 Budget constraint

The representative household earns income by supplying labor to domestic firms and earns the wage rate w_{it}. At each point in time, the flow of income is either debited or credited based on the net-foreign asset position. The household spends its asset-adjusted labor income on consumption of the three goods; the budget constraint is

$$P_{ait}C_{ait} + P_{mit}C_{mit} + P_{sit}C_{sit} = w_{it}L_{it} - \zeta_{it}$$

where P_{bit} is the price of the composite good in sector b.

3.6 Trade

All international trade is subject to barriers that take the iceberg form. Country i must purchase $d_{bijt} \geq 1$ units of any individual good of sector b from country j in order for one unit to arrive; $d_{bijt} - 1$ units *melt* away in transit. The trade barriers vary across sectors and over time. As a normalization I assume that $d_{biit} = 1$ for all (b, i, t). I also assume that the service sector is closed by setting d_{sijt} prohibitively high for all $i \neq j$ at all times t. In turn, country i purchases each variety z_b from its least cost supplier.

3.7 Equilibrium

A competitive equilibrium satisfies the following conditions: i) the representative household maximizes utility taking prices as given, ii) firms maximize profits taking prices as given, iii) each country purchases each variety from its least cost supplier and iv) markets clear. At each point in time, I take world GDP as the numéraire: $\sum_i w_{it}L_{it} = 1$ for all t. In line with the data, I focus on equilibria in which the subsistence constraint does not bind. I describe each equilibrium condition in detail below.

3.7.1 Household optimization

To ease notation I define an ideal price index for discretionary consumption, P_c, such that $P_cC = P_a(C_a - L\bar{c}_a) + P_mC_m + P_sC_s$. The ideal price index is given by

$$P_c = \left(\omega_a^{\varepsilon} P_a^{1-\varepsilon} + \omega_m^{\varepsilon} P_m^{1-\varepsilon} + \omega_s^{\varepsilon} P_s^{1-\varepsilon}\right)^{1/(1-\varepsilon)}$$

Final domestic expenditures on each good are given by

$$\begin{aligned} P_aC_a &= \omega_a^{\varepsilon}\left(\frac{P_a}{P_c}\right)^{1-\varepsilon}(wL - \zeta - LP_a\bar{c}_a) + LP_a\bar{c}_a \\ P_mC_m &= \omega_m^{\varepsilon}\left(\frac{P_m}{P_c}\right)^{1-\varepsilon}(wL - \zeta - LP_a\bar{c}_a) \\ P_sC_s &= \omega_s^{\varepsilon}\left(\frac{P_s}{P_c}\right)^{1-\varepsilon}(wL - \zeta - LP_a\bar{c}_a) \end{aligned}$$

3.7.2 Firm optimization

Markets are perfectly competitive, so firms set prices equal to marginal costs. Denote the price of variety z_b, produced in country j and purchased by country i, as $p_{bij}(z_b)$. Then $p_{bij}(z_b) = p_{bjj}(z_b)d_{bij}$, where $p_{bjj}(z_b)$ is the marginal cost of producing variety z_b 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 $p_{bi}(z_b) = \min_{j=1,\dots,I}[p_{bjj}(z_b)d_{bij}]$. The price of the sector b composite good in country i is then

$$P_{bi} = \gamma_b \left[\sum_k (u_{bk}d_{bik})^{-\theta_b} T_{bk}\right]^{-1/\theta_b} \tag{4}$$

where $u_{bi} = \left(\frac{w_i}{\nu_{bi}}\right)^{\nu_{bi}} \left[\prod_n \left(\frac{P_{ni}}{\mu_{bni}}\right)^{\mu_{bni}}\right]^{1-\nu_{bi}}$ is the unit cost for a bundle of inputs for producers in sector b in country i.

Next I define total factor usage in sector b by aggregating up across the individual goods.

$$L_{bi} = \int L_{bi}(z_b)\varphi_b(z_b)dz_b$$
$$M_{bni} = \int M_{bni}(z_b)\varphi_b(z_b)dz_b$$
$$Y_{bi} = \int y_{bi}(z_b)\varphi_b(z_b)dz_b$$

where $\varphi_b = \prod_i \varphi_{bi}$ is the joint density for productivity draws across countries in sector b (φ_{bi} is country i's density function). The term $L_{bi}(z_b)$ denotes the quantity of labor employed in the production of variety z_b. If country i imports good z_b, then $L_{bi}(z_b) = 0$. Hence, L_{bi} is the total quantity of labor employed in sector b in country i. Similarly, M_{bni} denotes the quantity of good n that country i uses as an intermediate input in production in sector b and Y_{bi} is the quantity of the sector b output produced by country i.

Cost minimization by firms implies that, within each sector, factor expenses exhaust the value of output.

$$w_i L_{bi} = \nu_{bi} P_{bi} Y_{bi}$$
$$P_{ni} M_{bni} = (1 - \nu_{bi})\mu_{bni} P_{bi} Y_{bi}$$

3.7.3 Trade flows

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

$$\pi_{bij} = \frac{(u_{bj} d_{bij})^{-\theta_b} T_{bj}}{\sum_k (u_{bk} d_{bik})^{-\theta_b} T_{bk}} \tag{5}$$

3.7.4 Market clearing conditions

I begin by describing the domestic market clearing conditions.

$$\sum_n L_{ni} = L_i$$

$$C_{bi} + \sum_n M_{nbi} = Q_{bi}, \text{ for each } b \in \{a, m, s\}$$

The first condition imposes that the labor market clear in country i. The second condition requires that the use of composite good b equal its supply. It's use consists of consumption by the representative household and intermediate use by firms in each sectors. 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,

$$P_{bi}Y_{bi} = \sum_j \left(P_{bj}C_{bj} + \sum_n P_{bj}M_{nbj} \right) \pi_{bji}$$

Finally I impose an aggregate resource constraint in each country: the sum of net exports across sectors must equal the value of net lending.

$$\zeta_i = \sum_b \underbrace{P_{bi}Y_{bi} - P_{bi}Q_{bi}}_{\text{Net exports in sector } b}$$

Net exports in each country equals the value of gross output minus the value of total spending by households and firms.

3.8 Qualitative implications for structural change

Each economy admits an aggregate input-output structure that links final demand in each sector (final domestic expenditures plus net exports) with sectoral output. Let $V_{bit} = w_{it}L_{bit}$ denote value added in sector b, $E_{bit} = P_{bit}C_{bit}$ denote final domestic expenditures in sector b, $N_{bit} = \sum_{j \neq i} (P_{bj}Q_{bj}\pi_{bijt} - P_{bi}Q_{mi}\pi_{bjit})$

denote net exports in sector b and define $\Upsilon_{nbi} = (1 - \nu_{ni})\mu_{nbi}\left(\frac{\nu_{bi}}{\nu_{ni}}\right)$. Then the aggregate input-output table in country i at time t can be shown to be given by

$$\underbrace{\begin{bmatrix} V_{ait} \\ V_{mit} \\ V_{sit} \end{bmatrix}}_{V_{it}} = \underbrace{\begin{bmatrix} \Upsilon_{aai} & \Upsilon_{mai} & \Upsilon_{sai} \\ \Upsilon_{ami} & \Upsilon_{mmi} & \Upsilon_{smi} \\ \Upsilon_{asi} & \Upsilon_{msi} & \Upsilon_{ssi} \end{bmatrix}}_{\Upsilon_i} \underbrace{\begin{bmatrix} V_{ait} \\ V_{mit} \\ V_{sit} \end{bmatrix}}_{V_{it}} + \underbrace{\begin{bmatrix} \nu_{ai} & 0 & 0 \\ 0 & \nu_{mi} & 0 \\ 0 & 0 & \nu_{si} \end{bmatrix}}_{\Phi_i} \underbrace{\begin{bmatrix} E_{ait} \\ E_{mit} \\ E_{sit} \end{bmatrix}}_{E_{it}} + \underbrace{\begin{bmatrix} \nu_{ai} & 0 & 0 \\ 0 & \nu_{mi} & 0 \\ 0 & 0 & \nu_{si} \end{bmatrix}}_{\Phi_i} \underbrace{\begin{bmatrix} N_{ait} \\ N_{mit} \\ N_{sit} \end{bmatrix}}_{N_{it}} \quad (6)$$

More compactly,

$$V_{it} = (I - \Upsilon_i)^{-1}\Phi_i(E_{it} + N_{it}) \quad (7)$$

The above input-output structure, which can also be found in Uy, Yi, and Zhang (2013), provides the basic framework through which I will evaluate structural change. Changes in fundamentals, i.e., productivity and trade barriers, generate changes in the composition of final demand (final domestic expenditures and net exports), while changes in the composition of final demand translate into changes in the composition of value added via the input-output structure. Recall that the input-output coefficients are constant throughout time but differ across countries. As such, all else equal, given similar changes in the composition of final demand across countries, each country may have a different response in terms of the composition of value added.

As noted, changes in final demand are the result of changes in the fundamentals of the economy. However, given similar changes to fundamentals in each country, the response of the composition of final demand may differ because of the relative importance of two distinct channels: final domestic expenditures and net exports.

4 Data and calibration

In this section I describe the data and the calibration strategy. I classify the three broad sectors of the economy using the "International Standard Industrial Classification of All Economic Activities, Rev. 3" (ISIC). The agricultural sector corresponds to ISIC categories A (Agriculture, hunting and forestry) and B (Fishing). The industrial sector corresponds to ISIC categories C (Mining and quarrying), D (Manufacturing) and E (Electricity, gas and water supply). Finally, the service sector corresponds to the remainder of economic activity—ISIC categories F-Q.

4.1 Data

The data set covers 108 countries from 1970-2011. I aggregate the individual countries up to three country groups: ADV (advanced economies), EMA (emerging Asia) and ROW (rest of the world). ADV consists of 22 countries: Australia, Austria, Belgium, Canada, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Netherlands, Norway, New Zealand, Portugal, Spain, Sweden, Switzerland, United Kingdom and United States. EMA consists of 9 countries: China, Hong Kong, India, Indonesia, Malaysia, Singapore, South Korea, Thailand and Taiwan. ROW consists of 77 countries. Those countries, as well as details on the sources of the data and the aggregation methodology, are provided in appendix A.

My choice for assigning countries into groups is guided by four important features of the data. First, ADV and EMA both contain countries that exhibit a strong dynamic relationship between development and the composition of value added as measured in Section 2, ROW does not. Second, ADV and EMA are on opposite ends of the income distribution. Third, each country in EMA experienced an increase in industry's share in value added, while each country in ADV experienced a decrease. Finally, the input-output coefficients differ between countries in EMA and countries in ADV.

Table 2 reports the composition of value added for each of the country groups in 1970 and in 2011, along with the GDP per capita. All economies experienced a decline in agriculture's share in value added from 1970-2011. The decline in ADV was much smaller than in EMA or in ROW since agriculture started at a much lower share. All economies also experienced an increase in service's share in value added. Finally, ADV realized a decline in industry's share in value added, while EMA realized an increase. Industry's share in ROW exhibits no clear trend through the period, although overall it declined by 3 percentage points. None of these aggregated economies exhibit a hump shape in industry's share individually, although the panel collectively does exhibit a hump shape.

Table 2: Composition of value added and GDP per capita from 1970 to 2011

Country group	Agriculture	Industry	Services	GDP per capita
ADV	0.04 $\searrow$ 0.01	0.30 $\searrow$ 0.18	0.66 $\nearrow$ 0.81	15.21 $\nearrow$ 35.86
EMA	0.37 $\searrow$ 0.11	0.27 $\nearrow$ 0.35	0.36 $\nearrow$ 0.54	1.15 $\nearrow$ 6.59
ROW	0.18 $\searrow$ 0.08	0.28 $\rightsquigarrow$ 0.25	0.54 $\nearrow$ 0.67	3.06 $\nearrow$ 6.43

Note: There are no hump shapes in the aggregated economies individually. $\nearrow$ represents a monotonic trend increase, $\searrow$ represents a monotonic trend decrease and $\rightsquigarrow$ represents non-monotonic and roughly constant. Value added is measured at current prices and GDP per capita is measured using expenditure-side PPPs in thousands of 2005 U.S. dollars.

4.2 Calibration

I separate the calibration exercise into three components: 1) common parameters, 2) economy-specific parameters (constant over time) and 3) time-varying parameters. As it will become clear, the values of the time-varying parameters depend on the values of the common parameters and the economy-specific parameters.

Common parameters The parameters that are common across countries and constant over time are the preference parameters, $\omega_a, \omega_m, \omega_s, \varepsilon$ and $\bar{c}_a$, the sector-specific shape parameters for the Fréchet distributions, θ_a, θ_m

and θ_s (I refer to these as the trade elasticities from now on) and the elasticity of substitution between the individual goods within the composite good, η. The parameter values are listed in Table 3.

To estimate the preference parameters I make use of cross-country price and expenditure data from the World Bank's International Comparison program (ICP). I exploit cross-country variation in internationally comparable prices for 109 goods across 145 countries for the year 2005 along with each country's final domestic expenditure on each of those goods. I classify each good into one of three sectors: agriculture, industry and services.

I construct sectoral prices for each country i by aggregating across all goods within a sector. For instance, let G_a denote the basket of goods in sector a and let g denote a particular good in that basket. The ICP reports a price for each good P_{gi} in country i, the expenditure in current U.S. dollars on each good, E_{gi} as well as the expenditures at purchasing power parity (PPP) which are computed as $R_{gi} = E_{gi}/P_{gi}$. For sector a I compute the total expenditures in U.S. dollars as $E_{ai} = \sum_{g \in G_a} E_{gi}$ and the total expenditures at PPP as $R_{ai} = \sum_{g \in G_a} R_{gi}$. I then define the sector a price as $P_{ai} = E_{ai}/R_{ai}$. I do the same procedure for sectors m and s. I treat the final consumption aggregate as the union of all the goods in all three sectors in order to compute the price index for consumption so that $P_{ci} = \frac{\sum_g E_{gi}}{\sum_g R_{gi}}$.

I estimate the preference parameters via nonlinear least squares. Specifically, I minimize the distance between the actual expenditures observed in the ICP and the sectoral expenditures implied by the first order conditions using the ICP prices from the data.

$$\min_{\omega_a, \omega_m, \omega_s, \bar{c}_a} \sum_i \left(\omega_a^{\varepsilon} \left(\frac{P_{ai}}{P_{ci}} \right)^{1-\varepsilon} \left(\sum_b E_{bi} - L_i P_{ai} \bar{c}_a \right) + L_i P_{ai} \bar{c}_a - E_{ai}, \right)^2$$
$$+ \left(\omega_s^{\varepsilon} \left(\frac{P_{si}}{P_{ci}} \right)^{1-\varepsilon} \left(\sum_b E_{bi} - L_i P_{ai} \bar{c}_a \right) - E_{si} \right)^2$$
$$\text{s.t. } \omega_a, \omega_m, \omega_s, \varepsilon, \bar{c}_a \geq 0 \text{ and } \omega_a + \omega_m + \omega_s \leq 1$$

Following Herrendorf, Rogerson, and Valentinyi (2013) (HRV henceforth), I estimate a transformation of the parameters to make the optimization problem unbounded. I estimate $\beta_1, \beta_2, \beta_3$ and β_4 with $\varepsilon = e^{\beta_1}, \omega_a = \frac{1}{1+e^{\beta_2}+e^{\beta_3}}, \omega_m = \frac{e^{\beta_2}}{1+e^{\beta_2}+e^{\beta_3}}, \omega_s = \frac{e^{\beta_3}}{1+e^{\beta_2}+e^{\beta_3}}$ and $\bar{c}_a = e^{\beta_4}$. The estimation yields $\varepsilon = 0.43$, $\omega_a = 0.01$ and $\omega_s = 0.67$ ($\omega_m = 1 - \omega_a - \omega_s = 0.32$). The estimated subsistence parameter implies that the subsistence share in ADV consumption of agriculture is $L\bar{c}_a/C_a = 0.24$ in 2005.

Table 3: Common parameters

Preference parameters				
$\omega_a = 0.01$	$\omega_m = 0.32$	$\omega_s = 0.67$	$\varepsilon = 0.39$	$\bar{c}_a = 1.48$
Variation in productivity draws				
$\theta_a = 4$	$\theta_m = 4$	$\theta_s = 4$		
Elasticity of substitution between individual goods within the composite good				
$\eta = 4$				

Note: The calibrated subsistence parameter implies that the share of substance in agricultural consumption in ADV in 2005 is $L\bar{c}_a/C_a = 0.24$.

My estimates differ from those in HRV. They estimate the preferences using a "final domestic expenditures" approach and a "consumption value added approach". In their final domestic expenditures approach, consumption of agriculture really means consumption of food, which includes spending on retail (the store that sold the food). Their consumption value added approach separates the retail component from food purchases and attributes only the value added component of agriculture to agricultural consumption and attributes the retail component to services consumption.

The final domestic expenditures in my model correspond exactly to what one would measure from the final demand column of an input-output table and, therefore, do not coincide with the final domestic expenditures approach in HRV. In that sense, the preferences in my model are defined over the value-added characteristics of the goods. However, I do not work with value-added production functions.

My estimate of the elasticity of substitution is much higher than the estimate in HRV; their estimate is close to zero using the value-added approach.

Comin, Lashkari, and Mestieri (2015) estimate the elasticity of substitution to be 0.57 under more general preferences using panel data and a value-added approach. There are other factors that contribute to differences in my estimates and those of HRV. First, I assume that there is no subsistence parameter in services, whereas HRV estimate a negative substance in services. Second, I include the construction sector in services, whereas HRV include construction in the industrial sector. Third, final domestic expenditures in my model include investment and government spending, whereas HRV use only household consumption data. Finally, HRV focus on time series data from the U.S. only, whereas I use cross-country data for 2005 only.

Next I assign values for the trade elasticities in each sector. The variation in productivity draws in sector b is governed by the shape parameter for the Fréchet distribution, θ_b. Simonovska and Waugh (2014) estimate this parameter for merchandise goods (agriculture plus industry in my model) to be 4. As such, I set $\theta_a = \theta_m = 4$. The values of θ_a and θ_m matter a lot for the counterfactual implications of the model because these values govern how sensitive bilateral trade shares are to changes in relative marginal costs. I set $\theta_s = 4$, although the value of θ_s is irrelevant since there is no trade in services. All that matters is T_{si}^{1/θ_s} and the calibrated value for this whole term is independent from the value for θ_s.

Finally, 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 I set $\eta = 4$.

Economy-specific parameters All of the coefficients in the production functions are specific to each economy: the share of value added in total output in each sector, ν_{bi} for $b \in \{a, m, s\}$ and the intermediate input shares in each sector, μ_{bni}, for $(n, b) \in \{a, m, s\}$. The parameter values are reported in Table 4.

I compute each of these shares directly for individual countries within the economy groups using the World Input-Output Database (WIOD). I take the average value between 1995-2011 for each country's coefficient. I compute ν_{bi}

as the value added in sector b divided by gross output of sector b. I compute the intermediate input share, μ_{bni}, as the value of intermediate goods from sector n used in the production of goods in sector b, divided by the total value of intermediate goods used by sector b. For countries that are not in WIOD, I impute each parameter by extrapolating based on a cross-country regression of the given parameter against GDP per capita for the countries in WIOD. Finally, to aggregate countries up to economy groups, I take the average parameter value across members within the group, weighted by real expenditure-side GDP at chained PPPs in 1995.

There are two sharp contrasts between advanced economies and emerging Asian economies regarding the input-output structure. First, the share of value added in total output for agricultural production, ν_a, is much higher in emerging Asia than it is in advanced economies. This reflects the fact that advanced economies rely more intensively on intermediate inputs, such as fertilizer and pesticides, while emerging Asian economies utilize more labor-intensive farming techniques. Second, the intensity of industrial inputs used in the production of services, μ_{ms} is much higher in emerging Asia than it is in advanced economies. Correspondingly, the share of services used in the production of services, μ_{ss}, is lower in emerging Asia than it is in advanced economies.

Table 4: Economy-specific parameters: production coefficients

	ν_a	ν_m	ν_s						
ADV	0.461	0.345	0.599						
EMA	0.625	0.278	0.529						
ROW	0.560	0.310	0.597						
	μ_{aa}	μ_{am}	μ_{as}	μ_{ma}	μ_{mm}	μ_{ms}	μ_{sa}	μ_{sm}	μ_{ss}
ADV	0.265	0.379	0.356	0.049	0.614	0.337	0.005	0.247	0.749
EMA	0.350	0.419	0.231	0.086	0.709	0.205	0.032	0.500	0.467
ROW	0.343	0.401	0.256	0.091	0.640	0.269	0.016	0.393	0.591

Note: ν_{bi} is the share of value added in gross output in sector b in country i. μ_{bni} is the share of sector n in the total intermediate demand by b in country i: $\sum_n \mu_{bn} = 1$ for each b.

Time-varying parameters Parameters that vary across time are the labor endowment, L_{it}, aggregate net exports, ζ_{it}, fundamental productivity in each sector, T_{bit} and the bilateral trade barriers in each sector, d_{bijt}.

I compute the labor endowment in each economy as the size of the population. Aggregate net exports in economy i are given by $\zeta_i = \sum_b \sum_j (X_{bji} - X_{bij})$, where X_{bij} is the gross value of trade from economy j to economy i in sector $b \in \{a, m\}$. The trade data that I use does not include trade in services.

The sectoral fundamental productivities and the trade barriers are unobservable. I pick the entire time series for each of these parameters so that the model matches the following: the composition of value added across sectors, GDP per capita and the bilateral trade shares, for each economy at each point in time.

I have data on value added and net exports by sector, for each economy, at all points in time as well as the input-output coefficients. I do not, however, have data on final domestic expenditures across time for each sector and each economy. Using the aggregate input-output table for each country, equation (6), or more compactly equation (7), I rearrange to solve for the final domestic expenditures as $E_{it} = \Phi_i^{-1}(I - \Upsilon_i)V_{it} - N_{it}$. By construction, the final domestic expenditures include both private and public consumption and investment.

Given the imputed expenditures, $E_{it} = (E_{ait}, E_{mit}, E_{sit})'$, I impute prices for each sector in each economy across time using the first order conditions of the representative household and the definition of the ideal price index for consumption. This step relies crucially on the fact that the elasticity of substitution between the goods is different from one. Taking $\bar{c}_a$ as given, I solve for P_{ait}, P_{mit} and P_{sit} by solving three equations:

$$
\begin{aligned}
E_{ait} &= \omega_a^{\varepsilon} \left(\frac{P_{ait}}{P_{cit}}\right)^{1-\varepsilon} (w_{it}L_{it} - \zeta_{it} - L_{it}P_{ait}\bar{c}_a) + w_{it}L_{it}P_{ait}\bar{c}_a \\
E_{sit} &= \omega_s^{\varepsilon} \left(\frac{P_{sit}}{P_{cit}}\right)^{1-\varepsilon} (w_{it}L_{it} - \zeta_{it} - L_{it}P_{ait}\bar{c}_a) \\
\left(\frac{P_{cit}}{w_{it}}\right)^{1-\varepsilon} &= \omega_a^{\varepsilon} \left(\frac{P_{ait}}{w_{it}}\right)^{1-\varepsilon} + \omega_m^{\varepsilon} \left(\frac{P_{mit}}{w_{it}}\right)^{1-\varepsilon} + \omega_s^{\varepsilon} \left(\frac{P_{sit}}{w_{it}}\right)^{1-\varepsilon}
\end{aligned}
$$

where w_{it}/P_{cit} is the expenditure-side real GDP per capita at chained PPPs in economy i at time t, which I take from the data and w_{it} is aggregate value added (GDP) per capita at current prices.[4]

The next step is to recover the productivity from the imputed relative prices. Using equations (4) and (5), the price of the sector b composite good can be expressed as

$$P_{bit} = \frac{u_{bit}}{Z_{bit}}$$

where $u_{bit} = \left(\frac{w_{it}}{\nu_{bi}}\right)^{\nu_{bi}} \left[\prod_n \left(\frac{P_{nit}}{\mu_{bni}(1-\nu_{bi})}\right)^{\mu_{bni}}\right]^{1-\nu_{bi}}$ is the cost of a bundle of inputs for producers in sector b. The term $Z_{bit} = \gamma_b^{-1}(T_{bit}/\pi_{biit})^{1/\theta_b}$ is the measured productivity in sector b in economy i at time t. Therefore, I can solve for measured productivity as a function of the prices (three equations in three unknowns) as follows

$$Z_{bit} = \left(\frac{1}{P_{bit}}\right)\left(\frac{w_{it}}{\nu_{bi}}\right)^{\nu_{bi}} \left[\prod_n \left(\frac{P_{nit}}{\mu_{bni}(1-\nu_{bi})}\right)^{\mu_{bni}}\right]^{1-\nu_{bi}}, \; b \in \{a, m, s\}$$

I then recover the fundamental productivity as $T_{bit}^{1/\theta_b} = (\gamma_b Z_{bit})\pi_{biit}^{1/\theta_b}$ by taking π_{biit} from the data. As discussed in Finicelli, Pagano, and Sbracia (2012), measured productivity depends on both the fundamental productivity and the home trade share. If the home trade share is smaller, measured productivity will be higher, reflecting the ability of an economy to import more varieties for which foreign producers are comparatively better at producing.

Note that there are two steps in which sectoral linkages play a crucial role in determining the magnitude of the inferred sectoral productivity levels. The first is in recovering the sectoral final domestic expenditures using the input-output identity. The second is in recovering measured productivity from the prices. The importance of considering sectoral linkages in the context of measuring productivity has been emphasized by Duarte and Restuccia (2014).

Table 5 reports the initial levels for fundamental productivity in each sector in each economy, as well as the average annual geometric growth rate in the

[4]The aggregate resource constraint implies that $\sum_b E_{bit} = w_{it}L_{it} - \zeta_{it}$.

fundamental productivity from 1970-2011. The productivity levels vary systematically with GDP per capita across economies within each sector. Consistent with the large literature on economic development, cross-country productivity differences are larger in agriculture than in other sectors (see Restuccia, Yang, and Zhu, 2008; Gollin, Lagakos, and Waugh, 2014, among others). In each of the economies, productivity growth is highest in agriculture.

Table 5: Time-varying parameters

	Fundamental productivity					
	Agriculture		Industry		Services	
ADV	40.10	(6.04%)	2.47	(2.84%)	2.39	(-0.12%)
EMA	8.56	(3.70%)	1.05	(1.48%)	0.62	(1.76%)
ROW	16.71	(2.09%)	1.45	(1.42%)	0.89	(0.22%)
	Bilateral trade barriers					
Agriculture	ADV	EMA	ROW			
ADV	—	5.41	2.83			
EMA	2.94	—	3.21			
ROW	3.40	6.08	—			
Industry	ADV	EMA	ROW			
ADV	—	4.78	3.81			
EMA	1.17	—	2.35			
ROW	1.27	3.89	—			

Note: The table reports the level of fundamental productivity in 1970 and the growth rate in parentheses. The bilateral trade barriers reported are the average of each barrier throughout time; the row indicates the importer and the column indicates the exporter.

The last thing to do is to calibrate the 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 locations as given.

$$d_{bijt} = \left(\frac{\pi_{bijt}}{\pi_{bjjt}}\right)^{-1/\theta_b} \left(\frac{P_{bit}}{P_{bjt}}\right)$$

For agriculture and industry, I make use of the data on bilateral trade shares,

π_{bijt} and the imputed prices, P_{bit}, to compute the bilateral trade barriers directly. In cases where $\pi_{bijt} = 0$, I set $d_{bijt} = 10^8$ (this is arbitrarily large enough to ensure that $\pi_{bijt} \approx 0$). In cases where the computed barrier is less than 1, I set $d_{bijt} = 1$. For services I set $d_{sijt} = 10^8$, for $i \neq j$, to generate no trade in services.

I report the average bilateral trade barriers from 1970-2011 in Table 5. Economies with lower GDP per capita face larger barriers to export industrial goods. This is a well-known feature that is needed in order to be consistent with cross-country prices and the pattern of trade (see Waugh, 2010; Mutreja, Ravikumar, Riezman, and Sposi, 2014). This feature is less striking within agriculture. The reason may be due, at least in part, to large subsidies for agricultural production in the U.S. and other advanced economies and larger restrictions on agricultural imports in developing economies.

With all of the parameters calibrated, I can compute the equilibrium of the model. Since I took the preference parameters as given in order to calibrate the productivities, I iterate on $\bar{c}_a$, at each iteration recomputing the productivities and trade barriers, until $L\bar{c}_a/C_a$ equals 0.24 in 2005 in ADV, the number obtained from the estimation of preference parameters.

5 Results

5.1 Model fit

The calibration makes use of data on value added at current prices in each sector, net exports at current prices in each sector, bilateral trade shares in each sector and aggregate GDP per capita (expenditure-side GDP at chained PPPs).

The model matches the composition of value added and GDP per capita over time in all economies almost perfectly. This is no surprise since the calibration was designed to do so. The model does very well on the trade dimension as well, by design. However, for EMA, there is some error in matching the home trade shares in industry. That is, the home trade share in industry for EMA is slightly high compared to the data; the reason is because of the restriction that $d_{bij} \geq 1$. In particular, from 1974-1991 the restriction binds for the trade barrier in industry from ADV to EMA. As such, the model produces less trade from ADV to EMA than is observed in the data and, hence, a larger home trade share in EMA. That being said, the average annual deviation from the data for $\pi_{m,EMA,ADV,t}$ is 0.03. In turn, the average deviation in the home trade shares in industry in EMA is also 0.03, which is small compared to the average value of the home trade share of 0.87.

The model almost perfectly replicates sectoral net exports over GDP. This may seem obvious given that the model was calibrated to match the bilateral trade shares, but the key to this result is the fact that the ratio of value added to gross output differs across economies. For instance, GDP is a value-added concept, while bilateral trade shares are constructed using gross trade flows and gross output. Hence, simultaneously matching both of these data requires being consistent with the ratio of value added to gross output in each sector and in each economy. In addition, matching both the net-export data as well as the GDP data requires allowing for aggregate trade imbalances.

5.2 The quantitative importance of sectoral linkages

As I documented above, the input-output linkages differ systematically across countries. In this subsection I expose the quantitative importance of these differences in accounting for structural change.

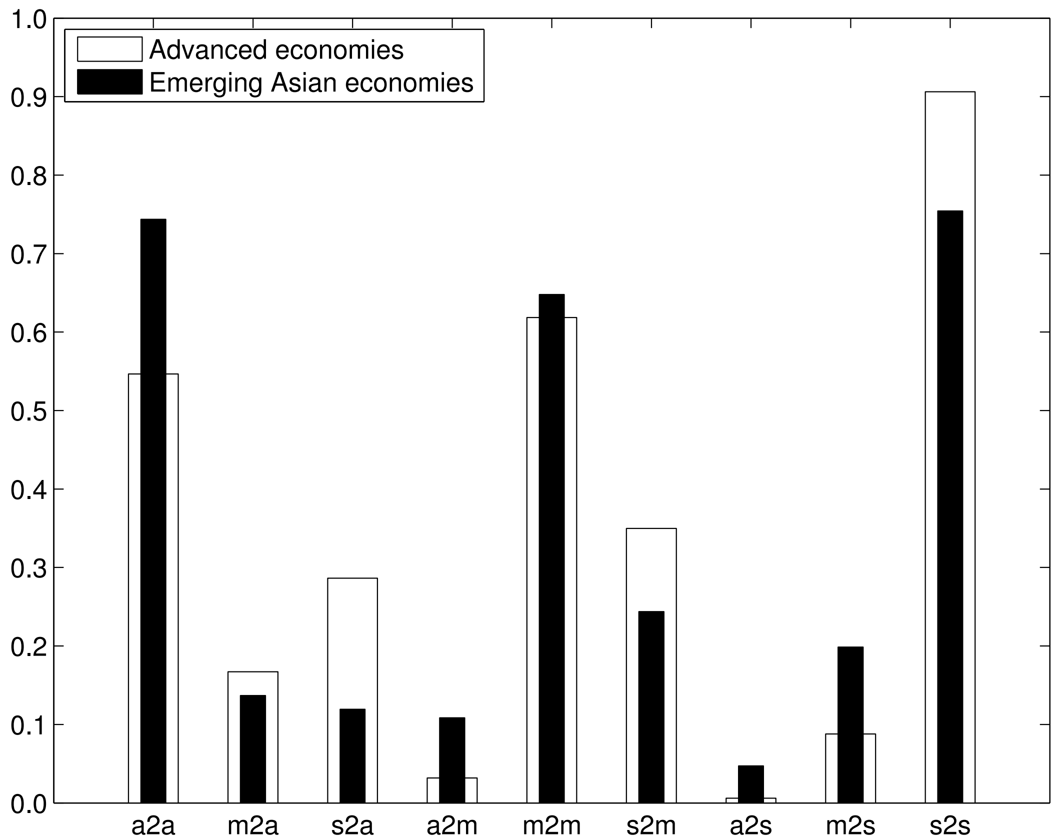
Exogenous forces in the model impact the composition of final demand via final domestic expenditures and net exports. In turn, a change in the composition of final demand maps into the composition of value added through the input-output structure. Recall equation (7), where $V_{it} = (i - \Upsilon_i)^{-1}\Phi_i(E_{it} + N_{it})$. In the input-output table, $(I - \Upsilon_i)^{-1}\Phi_i$ is known as the total requirements matrix. This matrix reveals how sensitive each sector's share in value added is in response to a change in the composition of final demand.

Figure 2 shows the coefficients of the total requirements matrix for advanced economies and emerging Asian economies. Specifically, the bars for 'm2s' denote the share of value derived from industry needed to satisfy one "dollar" worth of final demand of the services good. There are two notable differences between the two economies. First, the total (direct plus indirect) value of industrial goods required to deliver one dollar of services to the final consumer, 'm2s', is higher in EMA than in ADV. Indeed, this is accompanied by a larger total value of services required to deliver one dollar of services in ADV than in EMA, 's2s'. This reflects the fact that EMA utilizes industrial goods more intensively than ADV in the production of services; that is, because $\mu_{smEMA} > \mu_{smADV}$ and $\mu_{ssEMA} < \mu_{ssADV}$. This implies that if both economies experience an equal increase in service's share in final demand, the response of industry's share in value added will be larger in EMA than in ADV, while the response of service's share in value added will be larger in ADV than in EMA.

Second, the entire first row of the total requirements matrix is larger in EMA than in ADV—each of 'a2a','a2m' and 'a2s' are higher in EMA than in ADV—precisely because $\nu_{aEMA} > \nu_{aADV}$. This reflects the fact that ADV utilizes intermediate goods more intensively than EMA in the production of agricultural goods. As such, any change in derived demand for agriculture will initiate a stronger change in demand for agricultural employment in EMA than in ADV. The implication is that if both economies experience a similar decline in agriculture's share in final demand, then all else equal, agriculture's share in value added will fall more in EMA than in ADV and, in turn, EMA will experience a shaper increase in both industry's share and services share in value added.

One way to expose these effects is through the following counterfactual. Suppose that the total requirements matrix in emerging Asia was the same as that in advanced economies. Take the baseline path for the composition of final demand for EMA and ask how the composition of value added would have evolved if the total requirements matrix were the same as ADV. In EMA, industry's share in value added increased by 8.0 percentage points in the baseline, from 0.267 to 0.347. In the counterfactual, industry's share in value added would have increased by only 3.6 percentage points, from 0.236 to 0.272—

Figure 2: Total requirements matrix coefficients for advanced and emerging Asian economies



Note: m2s denotes the total share (direct plus indirect) of industrial goods required to produce one "dollar" worth of final demand for services. Therefore, a2s+m2s+s2s=1.

about 55 percent less than the baseline increase. Note that this counterfactual exercise does not hold the shares fixed in 1970. Altering the input-output coefficients translates into different levels of the composition of value added, holding fixed the composition of final demand. One may be concerned that the levels and the changes are not independent from one another—the higher the initial level of the share is, the less scope there is for the share to increase further. However, in the counterfactual, the level of industry's share in 1970 is lower than in the baseline, while the increase from 1970 to 2011 is smaller than in the baseline as well.

Now consider a similar counterfactual experiment going the other way; suppose that ADV had the same total requirements matrix as EMA. I feed in baseline composition of final demand for ADV and ask how the composition of value added would have evolved. In the baseline model, industry's share in value added declined by 12.0 percentage points, from 0.302 to 0.182. In the counterfactual experiment, industry's share in value added would have declined by only 9.6 percentage points, from 0.373 to 0.277—about 20 percent less than the baseline decline. Again, one may be concerned with the different levels influencing the changes in the shares. However, the level of industry's share in 1970 is higher in the counterfactual than in the baseline, yet, the total decline from 1970 to 2011 is still smaller in the counterfactual.

Discussion of the importance of sectoral linkages Around 55 percent of the increase in industry's share in value added in emerging Asian economies can be attributed to having a different input-output structure than advanced economies. Similarly, about 20 percent of the decline in industry's share in advanced economies can be attributed to having a different input-output structure than emerging Asian economies. These results shed new light on the asymmetries between advanced and emerging Asian economies regarding industry's share in value added. That is, given typical paths for the composition of final demand in both EMA and in ADV—a decline in agriculture's share and a rise in service's share—the two economies will experience different responses in the composition of value added.

This is a key departure from models that do not consider input-output linkages, such as Święcki (2014) and Comin, Lashkari, and Mestieri (2015). Without input-output structures, changes in the composition of final demand translate one-for-one into changes in the composition of value added. Embedding input output linkages, as is done in Uy, Yi, and Zhang (2013) alleviates the one-for-one mapping. In addition, as I have shown, allowing for differences in sectoral linkages across countries helps explain part of the hump shape in industry's share across levels of development.

5.3 Effect of domestic sectoral productivity growth

The previous results emphasized the importance of input-output linkages in transmitting changes in the composition of final demand into changes in the composition of value added. In this subsection I examine how changes in domestic productivity in each sector affect the domestic composition of final demand in each economy, via final domestic expenditures and net exports. I also report the net effect on the domestic composition of value added. In general, an increase in productivity in a given sector will tend to increase net exports over GDP in that sector and decrease that sector's share in final domestic expenditures. The goal of the following counterfactuals is to quantify the two opposing forces.

To accomplish this I shut down productivity growth in one economy and one sector and examine the evolution of the compositions in that economy. Mechanically, for a given sector b, I construct a counterfactual time path for fundamental productivity, $\tilde{T}_{bit}$, such that its average geometric growth rate is zero. Let $(1 + g_{bit}) = \left(\frac{T_{bit+1}}{T_{bit}}\right)^{1/\theta_b}$ be the period growth rate of fundamental productivity in the baseline model. In the counterfactual I set the level of the productivity equal to the baseline value in the initial period: $\tilde{T}_{bi1} = T_{bi1}$. I adjust the remainder of the path by constructing a counterfactual growth rate, $\tilde{g}_{bit}$, and compute $\tilde{T}^{1/\theta_b}_{bit+1} = (1 + \tilde{g}_{bit})\tilde{T}^{1/\theta_b}_{bit}$. Specifically, I define $1 + \tilde{g}_{bjt} = \frac{1+g_{bjt}}{1+\bar{g}_{bj}}$, where $1 + \bar{g}_{bi} = [\prod_t (1 + g_{bit})]^{\frac{1}{T-1}}$ is the average geometric growth rate in fundamental productivity in the baseline model, in sector b in economy i. By definition, the counterfactual growth rate has a geometric mean of zero throughout time. I feed in the counterfactual path for productivity for one economy i and one sector b, leave all other parameters at their baseline levels, and examine the implications for the relevant compositions in economy i only. I then repeat this exercise for each economy i and then for each sector b.

The results are reported in Table 6. Each row of the table displays the difference in each sector's share in its relevant composition, relative to the baseline, for the economy in which productivity growth is removed. I compute the differences as the average deviation in percentage points throughout time from the baseline value—the average vertical distance between the two curves in a time-series plot. The paths for the counterfactual shares do not intersect with the baseline baseline shares, except for the initial year where they are equal by construction. Therefore, a negative value implies that the counterfactual share lies below the baseline share throughout the sample period, while a positive value implies that the counterfactual share lies above the baseline value throughout the period.

Effects of domestic agricultural productivity growth on domestic compositions Removing agricultural productivity growth in any one economy leads to lower net exports of agriculture in that economy because of a loss in comparative advantage. It also implies a larger share of agriculture in final domestic expenditures for two reasons. The first is because the relative price of agriculture increases, relative to the baseline, and the Baumol effect leads to a larger share of final domestic expenditures on agriculture, relative to the baseline. The second is because aggregate income falls relative to the baseline and the income effect leads to a larger share of final domestic expenditures on agriculture because the relative subsistence requirement becomes tighter. In turn, the net effect on agriculture's share in final demand and value added is ambiguous.

It turns out that in ADV, the income effect is very small because the subsistence requirement is negligible. In addition, even with a higher relative price of agriculture, agriculture's share in final domestic expenditures is only slightly higher than in the baseline by 1.23 percentage points, on average. On the other hand, the loss in comparative advantage in agriculture results in lower net exports over GDP in agriculture. In particular, net exports over GDP in agriculture is, on average, 2.66 percentage points lower than in the baseline. The net effect is that agriculture's share in value added is, on average, 0.70 percentage points lower than in the baseline.

In EMA the income effect is substantial since subsistence accounts for a large share of agricultural consumption to begin with. Combined with the increase in the relative price of agriculture, agriculture's share in final domestic expenditures is 13.20 percentage points higher, on average, than in the baseline. However, agricultural net exports over GDP are, on average, 12.11 percentage points lower than in the baseline. The net effect is that agriculture's share in value added is, on average, 0.98 percentage points higher than in the baseline.

In both ADV and EMA, the net effect on agriculture's share in value added is very small. However, there is a more substantial effect on both industry's and service's share in value added, particularly in EMA. Since the agricultural goods are tradable, removing productivity growth also generates a Balassa-Samuelson effect that impacts the price of services relative to industrial goods. That is, as the productivity in agriculture falls in economy i , the aggregate wages fall relative to the baseline. Since industrial goods are tradable, the price of industrial goods does not fall by as much as the price of services, relative to the baseline. In turn, the price of services relative to industrial goods is lower than in the baseline and, hence, service's share in final domestic expenditures is substantially lower than in the baseline. Since industry's share in net exports is higher than in the baseline, the net effect is that industry's share in value added is higher compared to the baseline, while service's share in value added is lower than in the baseline.

Effects of domestic industrial productivity growth on domestic compositions Removing industrial productivity growth in any one economy leads to lower net exports of industrial goods in that economy. It also implies a larger share of industry in final domestic expenditures because the relative price of industrial goods increases. The net effect on the composition of value added differs between advanced and emerging Asian economies.

In ADV industry's share in final domestic expenditures is, on average, 9.99 percentage points higher than in the baseline; in EMA it is 4.55 percentage points higher than in the baseline. In ADV, industrial net exports over GDP are 5.33 percentage points lower, on average, relative to the baseline, while in EMA it is 3.36 percentage points lower than the baseline. The result is that, in ADV, industry's share in value added is 2.98 percentage points higher than in the baseline, while in ADV, industry's share in value added is 0.61 percentage points lower than in the baseline. That is, the net export channel played a more prominent role than the final domestic expenditure channel in EMA, while the converse was true for ADV.

Removing productivity growth in industry also leads to a Balassa-Samuelson effect. Removing industrial productivity growth in economy i implies lower wages, in economy i, relative to the baseline. Since agricultural goods are tradable, the price of agricultural goods does not fall by as much as the price of services. As a result, service's share in final domestic expenditures is lower than in the baseline, while agriculture's share in final domestic expenditures is higher than in the baseline. In addition, negative income effects that result from lower aggregate productivity imply a larger share of agriculture in final domestic expenditures. As expected, the income effect is larger in EMA than in ADV. Finally, agriculture's share in net exports is higher than in the baseline due to a shift in comparative advantage away from agricultural goods. The combined effect is that agriculture's share in value added is, on average, 2.90 percentage points higher than in the baseline in ADV and is 5.59 percentage points higher than the baseline in EMA. Service's share in value added is, on average, 5.88 percentage points lower than in the baseline in ADV and is 4.98 percentage points lower in EMA.

Positive productivity growth in industry generates a reallocation of final expenditures from industry towards services and a reallocation of net exports from agriculture to industry. While the net effect on industry's share in value added in EMA appears small, it is important to expose why it appears to be that way. That is, individually, both the final domestic expenditures channel and the net export channel have large quantitative responses to changes in sectoral productivity, but it turns out they they are somewhat offsetting with respect to industry's share in value added. However, both agriculture's share and service's share in value added change significantly.

The importance of the final domestic expenditures channel, relative to the net export channel, is stronger in ADV than in EMA. The reason is because improvements to industrial productivity in ADV have a significant impact on domestic relative prices since ADV is large and the composition of final domestic expenditures responds accordingly. While comparative advantage in ADV changes in response to industrial productivity growth, ADV is still large relative to its trading partners and, therefore, the response of net exports is limited. The opposite is true in EMA. Since EMA is relatively small compared to ADV, changes in EMA's productivity have lesser impact on its prices and, hence, a relatively smaller impact on final domestic expenditure shares. However, changes in productivity largely impact comparative advantage and, since EMA is relatively smaller than ADV, the changes in comparative advantage translate into larger changes in trade flows. This is the fundamental idea embedded in Uy, Yi, and Zhang (2013) in explaining the hump shape in South Korea's manufacturing employment share over time.

Effects of domestic service productivity growth on domestic compositions Services productivity growth has very little effect on the composition of net exports since services are not tradable. However, the composition of final domestic expenditures is impacted nontrivially. In EMA, eliminating services productivity growth results in higher relative price of services compared to the baseline. In turn, service's share in final domestic expenditures is, on average, 2.37 percentage points higher than in the baseline. Lower services productivity leads to lower income and the income effect results an agriculture's share in final domestic expenditures being, on average, 0.93 percentage points higher than in the baseline. In turn, industry's share in final domestic expenditures is 3.98 percentage points lower, on average, relative to the baseline. In ADV the effect is small, mostly because productivity growth in services is close to zero to begin with.

Summary of the effects of domestic productivity growth Positive productivity growth in a particular sector tends to i) decrease agriculture's share in final expenditures due to the income effect, ii) decrease that sector's

Table 6: Counterfactual implication of setting domestic productivity growth to zero in one sector: average percentage point difference relative to the baseline in domestic variables

	Sectoral shares in value added			Sectoral shares in final expenditures			$\frac{\text{Net exports}}{\text{GDP}}$		GDP per capita
	Agr	Ind	Srv	Agr	Ind	Srv	Agr	Ind	
Set domestic agricultural productivity growth to zero									
ADV	-0.70	1.32	-0.62	1.23	0.06	-1.29	-2.66	2.64	-2.72%
EMA	0.98	3.84	-4.82	13.20	-3.98	-9.21	-12.11	12.69	-7.58%
ROW	0.38	1.84	-2.22	5.13	-1.11	-4.01	-4.84	4.91	-4.15%
Set domestic industrial productivity growth to zero									
ADV	2.90	2.98	-5.88	0.13	9.99	-10.12	5.00	-5.33	-31.37%
EMA	5.59	-0.61	-4.98	1.67	4.55	-6.22	6.86	-3.36	-25.72%
ROW	3.83	-0.43	-3.40	0.72	4.04	-4.76	5.24	-5.02	-18.41%
Set domestic services productivity growth to zero									
ADV	0.00	-0.04	0.03	0.01	-0.07	0.07	-0.00	0.00	-0.23%
EMA	0.57	-1.50	0.93	0.93	-3.30	2.37	0.20	0.09	-26.52%
ROW	0.12	-0.38	0.26	0.18	-0.74	0.56	0.08	-0.05	-5.90%

Note: Each number in the table represents the average deviation over time of the counterfactual value from the baseline value in the economy in which productivity growth is shut down. For the sectoral shares, x_t, the reported number equals $\frac{100}{T}\sum_t x_t' - x_t$. For GDP per capita, y_t, the reported number equals: $\frac{100}{T}\sum_t \frac{y_t'-y_t}{y_t}$.

share in final domestic expenditures due to the Baumol effect and iii) increase net exports over GDP in that sector. Income effects are much larger in EMA than in ADV. Therefore, in response to economic growth, agriculture's share in value added declined faster in EMA than in ADV and, in turn, industry's share in EMA increased faster. In emerging Asian economies, the strength of the net export channel, relative to the final domestic expenditure channel, is larger than in advanced economies because of the relative size. Since EMA is smaller than ADV, domestic innovations have a relative smaller impact on relative prices, hence the allocation of final domestic expenditures. However, domestic innovations in EMA alter its comparative advantage and can change net exports substantially in response via international trade with larger economies.

5.4 Effect of foreign sectoral productivity growth

In this subsection I examine how changes in foreign productivity in each sector affect the composition of final domestic expenditures, domestic net exports over GDP and, in turn, the domestic composition of value added. That is, I isolate the effects of foreign sectoral productivity growth on each economy's composition of value added.

Removing productivity growth in either agriculture or industry in all foreign economies impacts the home economy primarily through the net export channel due to changing comparative advantage. There is very little impact on the composition of final domestic expenditures in any of the economies.

Upon removing foreign agricultural productivity growth, agricultural net exports over GDP in ADV are 0.99 percentage points higher, on average, than in the baseline. In EMA they are, on average, 6.10 percentage points higher than in the baseline. In both economies the higher agricultural net exports are accompanied by lower industrial net exports over GDP.

Upon removing foreign industrial productivity growth, industrial net exports over GDP in ADV are 0.60 percentage points higher, on average, than in the baseline. In EMA they are, on average, 3.55 percentage points higher than in the baseline. In both economies the higher agricultural net exports are accompanied by lower industrial net exports over GDP.

Removing service productivity growth in foreign economies has very little impact in domestic markets in any of the economies. The reason is because services are not traded.

From the perspective of advanced economies, the impact of foreign productivity growth on domestic allocations is trivial. Since ADV is large relative to its trading partners, innovations to comparative advantage can have a limited impact on its net exports, since most of its final demand is sourced domestically. EMA, however, is relatively small. Therefore, is foreign productivity growth is removed, EMA gains a comparative advantage relative to the baseline and significantly increases its net exports to satisfy foreign demand by large economies. These results implies that the process of structural change in emerging Asian economies has been influenced by developments in advanced economies and the rest of the world.

An increase in domestic productivity can have the same implication for comparative advantage as a decrease in foreign productivity. However, the two have vastly different effects on the composition of final domestic expenditures and on structural change overall. This aspect has not been explored in the literature as of yet. For instance, Uy, Yi, and Zhang (2013) utilize a two-country environment and study the implications for structural change in only one country. Świecki (2014) examines structural change across many countries in a multi-country environment, but does not isolate the effects of domestic versus foreign productivity growth on structural change on each country individually.

5.5 Assessing the role of international trade

The previous decompositions emphasized the role of two channels through which productivity growth affects structural change: the final domestic expenditure channel and the net export channel. Both channels were significantly affected by changes in productivity, yet, in some cases the two channels were somewhat offsetting and masked the importance of each channel individually.

To address the importance of international trade, I view the world from a closed-economy perspective. That is, I assume that there is no trade and I recalibrate the fundamental productivity parameters using the same procedure as before. The difference now is that I set the trade data to zero: $\pi_{bijt} = 0$ for $i \neq j, N_{bit} = 0$ for $b \in \{a, m, s\}$ and $\zeta_{it} = 0$. I also recalibrate the subsistence parameter so that the closed economy model generates $L\bar{c}_a/C_a = 0.24$ in ADV in 2005. This implies a subsistence parameter $\bar{c}_a = 1.51$, nearly identical to the subsistence term in the open economy model. I set $d_{bijt} = 10^8$ for all $i \neq j$ at all t and leave the remaining common parameters and economy-specific parameters at the same values as in the open economy calibration.

The calibrated paths for productivity are given in Table 7. Both the levels and the growth rates are almost identical to those calibrated in the open economy model.

Table 7: Time-varying parameters in a closed economy

	Fundamental productivity					
	Agriculture		Industry		Services	
ADV	43.23	(5.95%)	2.46	(3.06%)	2.40	(-0.18%)
EMA	8.63	(3.91%)	1.11	(1.28%)	0.59	(2.04%)
ROW	15.58	(2.14%)	1.55	(1.40%)	0.86	(0.31%)

Note: The table reports the level of fundamental productivity in 1970 and the growth rate in parentheses.

Indeed, if one uses the calibrated paths of fundamental productivity from the open economy and feeds them into the closed economy model, the implications for the composition of value added would be essentially indistinguishable from the open economy model. That is, simply moving to autarky by setting trade barriers restrictively high, leaving all other parameters at their baseline values, will yield similar implications for structural change as in the baseline open economy model. This implies that, from an accounting point of view, net exports do not explain much of the observed structural change.

This finding is consistent with Świecki (2014). He finds that trade is much less important for explaining structural change across many countries than productivity growth is. Nonetheless, trade does play a critical role since it is a key channel through which changes in productivity affect structural change.

In this exercise, domestic productivity growth affects only the composition of final domestic expenditures and not the composition of net exports, by construction. As a result, the net-export channel is inoperative and does not offset any of the changes on the composition of value added induced by changes in the composition of final domestic expenditures. The composition of final domestic expenditures changes drastically in each economy and, in turn, so does the composition of value added.

Removing domestic agricultural productivity growth results in a large increase in agriculture's share in value added, relative to the baseline, because of the Baumol effect and the income effect. In ADV, agriculture's share in value added is, on average, 1.25 percentage points higher than in the baseline, while in EMA it is 12.25 percentage points higher than in the baseline.

Removing industrial productivity growth results in large increases in industry's share in value added, relative to the baseline, purely due to the Baumol effect, with a small increase in agriculture's share because of income effects. In ADV, industry's share in value added is, on average, 5.85 percentage points higher than in the baseline, while in EMA it is 1.85 percentage points higher than in the baseline.

These results are in line with what the open economy results pointed to: the expenditure channel by itself is quite sensitive to changes in sectoral productivity because of relative price effects and income effects. Ignoring the net export channel would lead to both quantitatively and qualitatively vastly different predictions regarding the effects of the contribution of sector-specific productivity growth on the composition of value added. In particular, the closed economy model implies that improvements in industrial productivity in emerging Asia would have contributed negatively to industry's share in value added.

6 Conclusion

I construct a three-sector open economy model of structural change. I exploit the structure of the model to measure sectoral productivity across a large number of countries from 1970-2011. I then use the model as a laboratory to systematically evaluate the effects of location- and sector-specific productivity growth on the composition of output across the world. The results shed new light on the hump shape in industry's share across levels of development.

I find that the mapping between productivity growth and structural change differs systematically between advanced and emerging Asian economies for two reasons. First, taking changes in the composition of final demand as given, the composition of value added responds differently in emerging Asian economies than in advanced economies because of differences in input-output linkages. Given otherwise equal increases in service's share in final demand, emerging

Asian economies realized a larger increase in industry's share in value added than in advanced economies, since emerging Asian economies used industrial goods more intensively in the production of services than advanced economies.

Second, the composition of final demand in emerging Asian economies responds differently than that in advanced economies to sectoral productivity growth. The dichotomous relationship across emerging Asian economies and advanced economies can be explained by the relative importance of two components of final demand: final domestic expenditures and net exports. Improvements to industrial productivity in advanced economies tended to push resources away from industry since fewer resources were required to produce similar levels of output. Improvements to industrial productivity in emerging Asian economies tended to attract resources to the industrial sector to satisfy increased foreign demand for net exports. In addition, income effects played a more prominent role in emerging Asian economies than in advanced economies. As such, the rapid decline in agriculture's share in value added in emerging Asian economies contributed to the rise in industry's share.

Since net exports typically move in the opposite direction as final domestic expenditures as a result of changes in sector-specific productivity, gauging the effect of sector- and location-specific productivity growth on structural change through the lens of a closed-economy model can be misguided, both quantitatively and qualitatively, especially for emerging Asian economies.

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A Data

I first convert all data that are reported in local currency into U.S. dollars by using nominal exchange rates. In order to map all the data into model units, I divide all variables at current prices by world GDP at each point in time. Recall the world GDP is the numéraire in the model.

National accounts data and other aggregates I collect data on expenditure-side GDP at chained PPPs from version 8.0 of the Penn World Table (see Feenstra, Inklaar, and Timmer, 2013, (PWT80)). This is also the source of the data on population as well as nominal exchange rates that I use to convert all local currency variables into U.S. dollars.

I set the sequence of labor endowments to equal the total population in each country at each point in time. For the country aggregates in the model, I simply sum across all countries that belong to a group: $L_i = \sum_{g \in G_i} L_g$, where G_i denotes the set of countries that belong to group i and L_g denotes the population of member g. I use data on expenditure-side real GDP at constant PPPs for individual countries and aggregate up to the country groups using the same procedure as for labor endowments. I then use the ratio of the expenditure-side real GDP at chained PPPs and divide by population to construct GDP per capita (this corresponds to w/P_c in the model).

The empirical counterpart to the wage in the model is GDP per capita at current prices. The current-price GDP data comes from national accounts data of the PWT80 available at http://www.rug.nl/research/ggdc/data/penn-world-table.

Sectoral value added data I obtain sectoral value added in current prices and in constant prices for all countries, except for Taiwan, from the National Accounts and Main Aggregates Database of the United Nations (http://unstats.un.org/unsd/snaama/dnlList.asp). Data for Taiwan comes from the 10-sector database of the Groningen Growth and Development Center (GGDC) (see Timmer, de Vries, and de Vries, 2014). The sum of value added across sectors from the various databases often does not exactly match the total GDP data from the national accounts. To resolve this, I proportionately scale the sectoral value added numbers to make the sum match the total GDP in the national accounts. This way each sector's share in total value added is unchanged.

International trade data I employ annual bilateral trade data from the UN Comtrade database. The data are reported at the four-digit level using the "Standard International Trade Classification, Rev. 2" (SITC). I construct a correspondence to link the trade data to the value added data using my definition of agriculture and industry; the data does not report trade in services. The agricultural sector corresponds to SITC categories 001⋆, 0251, 041⋆, 043⋆, 044⋆, 045⋆, 054⋆, 057⋆, 0616, 0742, 075⋆, 0811, 0812, 121⋆, 2119, 212⋆, 222⋆, 223⋆, 268⋆, 273⋆, 278⋆, 28⋆⋆, 29⋆⋆, and 32⋆⋆,. The industrial sector corresponds with all remaining SITC categories that are non-agriculture.

I construct bilateral trade matrices for agriculture and industry, $X_{a,imp,exp}$ and $X_{m,imp,exp}$ for all country pairs where imp denotes the importing country and exp denotes the exporting country. I define the bilateral trade flows between country groups as $X_{bij} = \sum_{imp \in G_i} \sum_{exp \in G_j} X_{b,imp,exp}$, where G_i denotes the set of countries in country group i. Given the aggregated bilateral trade matrices, I construct net exports for each country group in each sector by computing total imports for country group i as $\sum_j X_{bij}$ and total exports as $\sum_j X_{bji}$.

Input-output data I exploit data from input-output tables to measure the share of value added in gross output and the intermediate input shares. Data are available for a subset of the countries from 1995-2011 from the World Input-Output Database: http://www.wiod.org/new_site/database/niots.htm (see Timmer, 2012).

Country groups I combine individual countries into three country groups: ADV (advanced economies), EMA (emerging Asia) and ROW (rest of the world). ADV consists of 22 countries: Australia, Austria, Belgium, Canada, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Netherlands, Norway, New Zealand, Portugal, Spain, Sweden, Switzerland, United Kingdom and United States.

EMA consists of 9 countries: China, Hong Kong, India, Indonesia, Malaysia, Singapore, South Korea, Thailand and Taiwan.

ROW consists of 77 countries: Albania, Argentina, Bahamas, Bangladesh, Barbados, Belize, Benin, Bolivia, Brazil, Bulgaria, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Chile, Colombia, Costa Rica, Côte d'Ivoire, Djibouti, Dominican Republic, Ecuador, Egypt, El Salvador, Fiji, The Gambia, Ghana, Guatemala, Guinea, Guinea-Bissau, Honduras, Hungary, Iceland, Iran, Israel, Jamaica, Jordan, Kenya, Laos, Lebanon, Liberia, Madagascar, Malawi, Mali, Malta, Mauritania, Mauritius, Mexico, Mongolia, Morocco, Mozambique, Nepal, Niger, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Rwanda, Saint Kitts and Nevis, Senegal, Sierra Leone, South Africa, Sri Lanka, Suriname, Syrian Arab Republic, Tanzania, Togo, Trinidad and Tobago, Tunisia, Turkey, Uruguay, Venezuela, Zambia and Zimbabwe.