

# Skill-Biased Structural Change and the Skill-Premium

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## Abstract

We document for a broad panel of advanced economies that increases in GDP per capita are associated with a shift in the composition of value added to sectors that are intensive in high-skill labor. It follows that further development in these economies leads to an increase in the relative demand for skilled labor. We develop a two-sector model of this process and use it to assess the contribution of this process of skill-biased structural change to the rise of the skill premium in the US over the period 1977 to 2005. We find that these compositional demands account for roughly 30% of the overall increase of the skill premium due to technical change.

## 1 Introduction

The dramatic increase in the wages of high skilled workers relative to low skilled workers is one of the most prominent secular trends in the US and other advanced economies in recent decades. The consensus view in the literature, as summarized in the review article by Acemoglu and Autor (2011)), is that the dominant factor generating this trend is skill-biased technological change (SBTC).<sup>1</sup> In this paper we argue that a distinct process – which we label skill-biased *structural* change – has also played a quantitatively important role. We

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<sup>1</sup>This is not to say that SBTC is the *only* factor at work, as the literature has also highlighted the effect of other factors on overall wage inequality. For example, DiNardo et al. (1996) argue that labor market institutions such as minimum wages and unionization have played an important role in shaping wage inequality overall, Feenstra and Hanson (1999) emphasize the role of offshoring, and Autor et al. (2013) emphasize the role of trade.

use the term skill-biased structural change to describe the systematic reallocation of sectoral value-added shares toward high-skill intensive industries that accompanies the process of continued development among advanced economies.

The economic rationale for the consensus view is based on simple demand and supply analysis in the context of what Acemoglu and Autor call the canonical model—an aggregate production function that has high-skilled and low-skilled labor as inputs. Because the relative supply of high-skilled labor has increased, an increase in the relative wage of high-skilled labor requires some force that increases the relative demand for high-skilled labor. But the only way to generate an increase in relative demand for high-skilled labor in the canonical model is via technical change that favors high-skilled workers.<sup>2</sup>

The economic intuition behind our result is equally simple, but it requires that one go beyond the aggregate production function approach in the canonical model. If, as we show is indeed the case in the next section, the process of development is systematically associated with a shift in the composition of value added toward sectors that are intensive in high-skill workers, then this process alone will increase the demand for high-skilled workers, independently of whether it is driven by skill-neutral or skill-biased technical change. With an aggregate production function, development that comes from skill-neutral technical change has no effect on the relative demand for high-skilled workers, so this channel is absent.

To assess the quantitative significance of this channel, we develop a simple general equilibrium model of structural transformation that incorporates an important role for skill and use it to study the evolution of the US economy between 1977 and 2005. In order to best highlight the shift in value added to high skill-intensive sectors, we study a two-sector model in which the two sectors are distinguished by their intensity of skill workers in production. We allow for sector specific technological change, which is a (sector-specific) combination of skill-neutral and skill-biased technical change. We show how the model can be used to infer preference parameters and the process for technical change using data on the change in the composition of employment by skill, the change in aggregate output, changes in sectoral factor shares, the skill premium, relative sectoral prices and the distribution of sectoral value added.

In the data, the skill premium increases from 1.37 to 1.65 between 1977 and 2005, an increase of 28 percentage points. Our calibrated model perfectly matches this increase. We then use the model to decompose this increase into three different components: one due to the changes in the relative supply of high-skill workers, one part that is due to skill-biased technical change, and a third part due to other technological changes. If there had been no change in technology, our model predicts that the skill premium would have decreased to .82, a drop of 55 percentage points, due to the increase in the relative supply

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<sup>2</sup>One can formulate richer structures in which the fundamental technical change is not explicitly skill biased but which operates like skill-biased technical change in a reduced form sense. For example, Krusell et al. (2000) stressed how the decreasing price of equipment coupled with capital-skill complementarity also serves to increase the relative demand for skill.

of high-skill workers. It follows that overall changes in technology created an increase in the skill premium of roughly 83 percentage points. In our benchmark specification, almost one third of this increase comes from changes in technology other than skill biased technical change, operating through their effect on the composition of value added. We conclude that systematic changes in the composition of value added associated with the process of development are an important factor in accounting for the rise in the skill premium. In fact, if skill-biased technical change had been the sole source of technical change over this period, our model predicts that the skill premium would have been essentially unchanged.

Our paper is related to many papers in two distinct literatures, one on SBTC and the skill premium and the other on structural transformation. An early contribution in the former literature is Katz and Murphy (1992), and an excellent recent overview is provided by Acemoglu and Autor (2011). Although Katz and Murphy predominantly use an aggregate production function to interpret the data, Section V of their paper does argue that changes in sectoral composition are an important element of the increased relative demand for skill. Except for their explicit consideration of international trade, they are otherwise agnostic about the driving forces behind these reallocations. Relative to them, our contribution is threefold. First, we document the importance of compositional effects that are systematically related to the process of development. Second, we show how to uncover the different dimensions of technological change in a multi-sector framework. Third, we present a general equilibrium model in which one can assess the driving forces behind compositional changes. It is also of interest to note that whereas their analysis ended in 1987, ours covers the period through 2005. An early contribution in the second literature is Baumol (1967), with more recent contributions by Kongsamut et al. (2001) and Ngai and Pissarides (2007). (See Herrendorf et al. (2014) for a recent overview.) Relative to this literature our main contribution is to introduce heterogeneity in worker skill levels into the analysis and to organize industries by skill intensity rather than broad sectors.

The paper that we are most closely related to is Buera and Kaboski (2012). Like us, they study the interaction between development and the demand for skill, though their primary contribution is conceptual, building a somewhat abstract model to illustrate the mechanism. Relative to them our main contribution is to build a simple model that can easily be connected to the data and to use the model to quantitatively assess the mechanism. An important antecedent of our work is the paper by Acemoglu and Guerrieri (2008). Like us, they study the relationship between development and structural change in a model that features heterogeneity in factor intensities across sectors. But differently than us, they focus on differential intensities for physical capital and the role of the relative price of physical capital rather than human capital. Their work is also primarily theoretical.

An outline of the paper follows. Section 2 presents aggregate evidence on the relation between development and the value added share for high skill intensive services in a panel of advanced economies, in addition to some other

important empirical patterns. Section 3 presents our general equilibrium model and characterizes the equilibrium. Section 4 shows how the model can be used to account for the evolution of the US economy over the period 1977 to 2005, and in particular how the data can be used to infer preference parameters and the process of technical change. Section 5 presents our main results about the contribution of various factors to the evolution of the skill premium. Section 6 concludes.

## 2 Empirical Motivation

This section provides motivating facts for the prevalence of what we refer to as skill-biased structural change. In particular, using data for a broad panel of advanced economies, we document two key facts. First, there is a strong positive correlation between the level of development in an economy, as measured by GDP per capita, and the share of value added that is attributed to high skill services. Second, there is also a strong positive correlation between the level of development and the price of high skill services relative to other goods and services. Interestingly, these relationships are very stable across countries, and in particular, the experience of the US is very similar to the average pattern found in the data.

We supplement the above aggregate time series evidence for a panel of countries with some evidence about cross-sectional expenditure shares in the US economy. In particular, we show that the expenditure of higher income households contains a higher share of skill-intensive value-added. This fact will serve two purposes. First at a qualitative level it is suggestive evidence of the role of a non-homotheticity in the demand for high skill services, which is a feature we will include in our model. Second, we will also show how this cross-sectional moment provides important information about preference parameters that is not readily available from aggregate time series data.

### 2.1 Aggregate Panel Evidence

The starting point for our analysis is the earlier work of Buera and Kaboski (2012). They divide industries in the service sector into two mutually exclusive groups: a high skill-intensive group and a low skill-intensive group, and show that whereas the value added share of the high-skill group rose substantially between 1950 and 2000, the value added share of the low-skill group actually fell over the same time period. This finding suggests that the traditional breakdown of economic activity in the structural transformation literature, into agriculture, manufacturing and services, was perhaps not well suited to studying the reallocation of economic activity in today's advanced economies. Here we pursue this line of work further, modifying their aggregation procedure to include goods-producing industries, and extending their analysis to a broad panel of advanced economies.

The analysis is based on underlying value added data from the EUKLEMS

Database (“Basic Table”)<sup>3</sup> These data exist in comparable form for a panel of 12 advanced economies over the years 1970-2005.<sup>4</sup> The sectoral value-added data are available at roughly the 1 to 2-digit industry level. We focus on a two-way split of industries into high skill intensive and low skill intensive based on the share of labor income paid to high-skill workers.<sup>5</sup> While one could imagine more detailed splits, including more than two skill categories and perhaps interacting skill intensity with goods vs. services, we feel that this two-way split both facilitates exposition and allows us to capture a robust pattern in the cross-country data.

The labor payment data come from the EUKLEMS Labour Input Data and are slightly more disaggregated. High skill-intensive service sectors are: “Financial Intermediation”, “Real Estate and Business Services”, “Education”, and “Health and Social Work”. In 1970, the economy-wide average share of labor compensation paid to high-skill workers in the U.S. was 20 percent; the corresponding shares for these high skill-intensive industries were 34, 38, 74, and 49 percent, respectively. These industries remain well above average throughout the time period.<sup>6</sup> We combine these data with real (chain-weighted) GDP per capita data from the Penn World Tables 7.1. Finally, we demean both the value-added share data and the (log) GDP per capita data by taking out country fixed effects.

Figure 1 shows the data pooled across time and countries. The small squares show the relationship for the panel of advanced countries; we have highlighted the United States data using the larger circles. The relationship is clear: the value added share of the high skill-intensive sector increases with log GDP/capita, with a highly significant (at a 0.1 percent level) semi-elasticity of 0.17. The regression line implies an increase of roughly 24 percentage points as we move from a GDP per capita of 10,000 to 40,000 (in 2005 PPP terms), and explains 80 percent of the variation in the data. Moreover, we see that the United States data is quite similar to the overall relationship. Indeed, the tight relationship suggests that cross-country differences in the details for funding of education or health, for example, are second order relative to the income per capita relationship. In sum, the tendency for economic activity to move toward high skill-intensive services as an economy develops is a robust pattern in the cross-country data.

One of the common explanations for structural change is changes in relative prices. (See, for example, Baumol (1967) and Ngai and Pissarides (2007).) Using value-added price indices from the same EUKLEMS Database, we can examine the correlation between the relative price of high-skill intensive services and the increasing value added share of high-skill intensive services that accompanies

<sup>3</sup>See O’Mahony and Timmer (2009).

<sup>4</sup>These countries are Australia, Austria, Denmark, France, Germany, Italy, Japan, the Netherlands, South Korea, Spain, the United Kingdom, and the United States. The U.S. data for value-added go back to only 1977, while the Japan data go back to only 1973.

<sup>5</sup>High-skill is defined as a college graduate and above.

<sup>6</sup>The next highest industries are “Chemicals and Chemical Products” (27 percent), “Coke, Refined Petroleum, and Nuclear Fuel” (21 percent), and “Electrical and Optical Equipment” (21 percent).

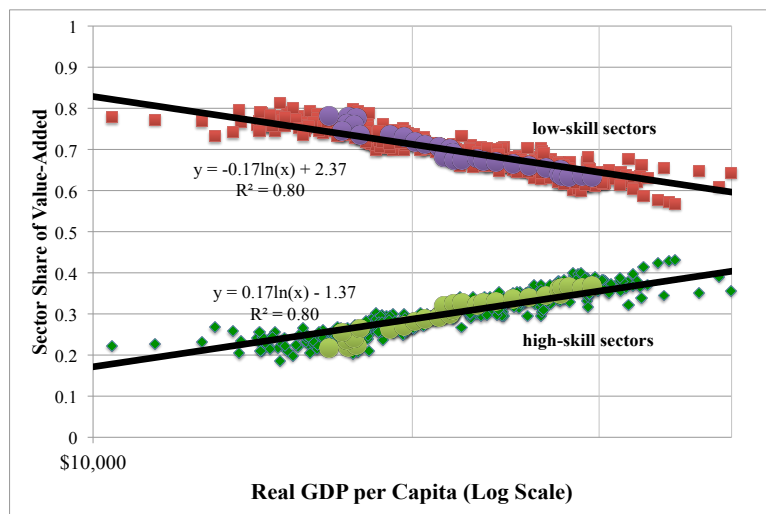


Figure 1: Value-added by Skill-intensity and Economic Development.

the process of development.<sup>7</sup> Figure 2 is analogous to Figure 1, but it plots the price index of the high skill-intensive sector relative to the low-skill intensive sector rather than share data on the y-axis. Again we have demeaned both the relative price and log GDP per capita data to eliminate country fixed effects, and normalized the relative price indices to 100 in 1995. As before, the larger circles represent the U.S. data.

Again, the relationship is striking. The linear regression is highly significant, explains 84 percent of the variation in the demeaned data, and is quantitatively important: the relative price of the high skill-intensive sector increases almost two and a half times over the range of the data. Finally, the U.S. relationship is quite similar to the overall relationship, and again the tight relationship suggests that cross-country variation in this relative price-income relationship is second order. We conclude that changes in relative prices are another robust feature of the structural transformation process involving the movement of activity toward the high-skill intensive sector.

## 2.2 Income Effects: Cross-Sectional Household Evidence

A second common explanation for structural change is income effects associated with non-homothetic preferences. (See, for example, Kongsamut et al. (2001).) With this in mind it is of interest to ask whether high-skill intensive services are

<sup>7</sup>We construct sector-level aggregate indices as chain-weighted Fisher price indices of the price indices for individual indices. Calculation details are available in the data appendix.

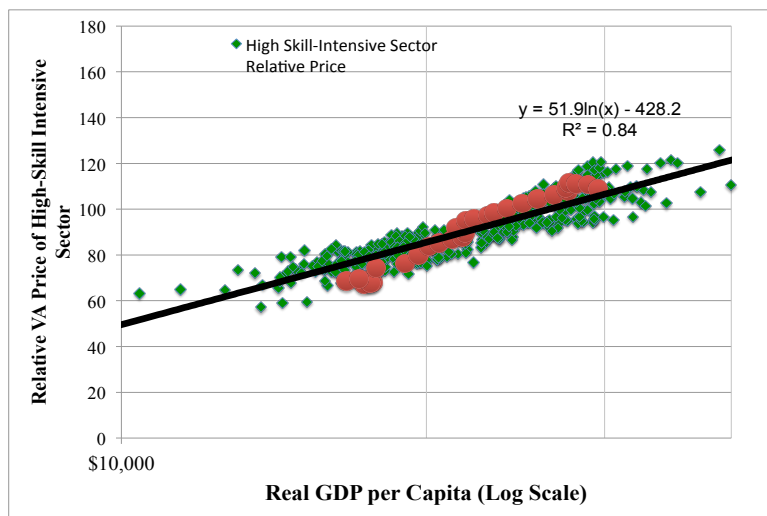


Figure 2: Relative Price of Skill-intensity Sector and Economic Development.

a luxury good, i.e., have an income elasticity that exceeds one. To pursue this we examine whether the relationship between the skill intensity of value-added consumption and income exists in the expenditure data from a cross-section of households. To the extent that all households face the same prices at a given point in time and have common preferences (or at least preferences that are not directly correlated with income), the cross-sectional expenditure patterns within a country abstract from the relative price relationship in Figure 2 and allow us to focus on the effect of income holding prices constant.

One complication with pursuing this approach is that it involves mapping household expenditure data through the input-output system in order to determine the consumption shares of value added. We briefly sketch the steps of this procedure here, and provide more details in the appendix. First, we start with the household level Consumer Expenditure Survey (CEX) data for the United States from 2012. We adapt a Bureau of Labor Statistics (BLS) mapping from disaggregate CEX categories to 76 NIPA Personal Consumption Expenditure (PCE) categories. We then utilize a Bureau of Economic Analysis (BEA) mapping of these 76 PCE categories to 69 input-output industries, that properly attributes the components going to distribution margins (disaggregated transportation, retail, and wholesale categories). Using the 2012 BEA input-output matrices, we can then infer the quantity of value added of each industry embodied in the CEX expenditures. Using the EUKLEMS data, we classify the 69 industries as high skill- or low skill-intensive.<sup>8</sup> We therefore have constructed

<sup>8</sup>The labour data from EUKLEMS contains 41 distinct industries. The "basic" data, from

a household-level data set of the amount of value added per dollar spent produced by high skill-intensive sectors and low skill-intensive sectors, which we can regress on household observables, most importantly income or education, and potentially a host of other household level controls. We restrict ourselves to the primary interview sample, and each observation is a household-month observation.

Table 1 presents results for regressions of the total share of expenditures that is high-skill intensive. The first column presents results from an OLS regression on log after tax income and a set of demographic controls, including age; age squared; dummies for sex, race, state, urban, and month; and values capturing household composition (number of boys aged 2-16, number of girls aged 2-16, number of men over 16, number of women over 16 years, and number of children less than 2 years). The coefficient on log income in the first column indicates that the semi-elasticity of the share of value-added embodied in expenditures is 0.012.

Table 1: **Household High-Skill Intensive Expenditure Share vs. Income**

	OLS	IV	OLS
<b>Ln Income</b>	0.012***	0.049***	.
<b>SE</b>	0.001	0.002	.
<b>High Skill Head</b>	.	.	0.043***
<b>SE</b>	.	.	0.002
$R^2$	0.08	0.02	0.15
<b>Observations</b>	48,550	48,550	17,812

\*\*\* indicate significance at the 1 percent level.

Controls include: age; age squared; dummies for sex, race, state, urban, and month; number of boys (2-16 year); number of girls (2-16 years); number of men (over 16 years); number of women (over 16 years); and number of infants (less than 2 years). High skilled is defined as 16 years of schooling attained, while low skilled is defined as 12 years attained.

Income is certainly mis-measured in the micro data, and even if properly measured it would only proxy for permanent income, leading to a likely attenuation bias. The second column attempts to alleviate this measurement error by instrumenting for log income using the years of schooling attained by the head of household. Instrumenting for income in this fashion increases the coefficient roughly four-fold to 0.049.

The last column uses education as a direct regressor, replacing log income with a dummy for whether the head of household is high skilled or not. Here high skill is defined as having exactly 16 years of education, while low skill is defined as having exactly 12 years. (The rest of the households are dropped from the sample.) The coefficient indicates that the share of value-added embodied in expenditures is 4.3 percentage points higher in households with a high-skilled head.

which we obtain value-added data, contain only 33 distinct industries.



We have examined the robustness of the results in Table 1 to alternatives. Table 1 uses monthly expenditures of the household, but if we aggregate household expenditures across the three months they are surveyed, we find nearly identical results. By defining high skill as those with at least 16 years of education, and low skill as those with less than 16 years of education, we expand the sample somewhat, but the raw estimates are similar (0.032 rather than 0.043).<sup>9</sup> Second, dropping demographic controls increases the sample by about 15 percent and lowers the coefficients on income somewhat (by roughly 50 percent), but the coefficients remain highly significant. Dropping the controls have essentially no impact on the high-skilled head of household coefficient. The main effect of dropping the controls is substantially lower  $R^2$  values.

Quantitatively, even the larger, instrumented, income coefficient of 0.049 is substantially smaller than the aggregate time series value of 0.17 in Figure 1, but not negligible in comparison. We therefore take this as suggestive evidence that, in addition to relative prices, non-homotheticities may also play a role in accounting for the observed pattern of skill-biased structural change.

While we do regard this evidence as suggestive, we want to note an important limitation in directly applying the micro elasticity as an income effect. Because the CEX captures only out-of-pocket expenditures, it underestimates the true consumption of certain goods like insurance premiums (a substantial share of which is paid by employers) and higher education (a substantial share of which is paid by government).<sup>10</sup>

### 2.3 Summary

In summary, we have documented a robust relationship in the time series data for advanced economies regarding the movement of activity into high-skill intensive services and the process of development. We will refer to this process as skill-biased structural transformation, so as to emphasize both its connection to the traditional characterization of structural transformation and the special role of skill intensity. This relationship is remarkably stable across advanced economies, thus suggesting that it is explained by some economic forces that are robustly associated with development, with country specific tax and financing systems not playing a central role in explaining the time series changes.

The traditional structural transformation literature emphasizes the role of both non-homotheticities and relative price changes as drivers of structural

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<sup>9</sup>An alternative analysis, however, where we try to directly estimate expenditure elasticities by regressing the (log) level of high-skill value-added on the (log) level of expenditures gives substantially higher estimates. This is driven by certain lumpy expenditures like higher educational expenses and car purchases driving both up in particular months. This motivates an emphasis on the relationship between the high skill share and education or income rather than direct expenditures per se.

<sup>10</sup>The estimated income semi-elasticity of the share of out-of-pocket insurance is actually significantly negative in the CEX data although overall insurance consumption is certainly positive. Similarly, although the expenditure share-income semi-elasticity of higher education is positive, it is likely understated. Finally, the lack of primary and tertiary expenditures may actually be overstated in the CEX data because it neglects public expenditures, but we conjecture that this relationship is small relative to the higher education relationship.

transformation, and we have also presented evidence that both of these effects are relevant in the context of skill-biased structural transformation as well. Specifically, we documented a strong positive correlation between the relative price of high skill intensive services and GDP per capita in a cross-country panel as well as a positive correlation between household value added expenditure shares on high skill intensive services in the US cross-section. These relationships are not only highly statistically significant, but they are also economically significant in a quantitative sense.

Finally, we should note that in documenting these relationships we have used a strict high versus low-skill dichotomy. This masks important within sector heterogeneity. Indeed, within the low-skill sector, a pattern emerges that the relatively more skill-intensive sectors, e.g., manufacturing industries like electrical equipment and chemicals expand relative to the less skill-intensive sectors like agriculture or textiles.<sup>11</sup> In this sense, our simple dichotomy may understate the true extent of skill-biased structural change. However, the relative price patterns, use patterns (consumption and investment), and trade patterns make the analysis at a more disaggregated level more difficult to interpret and much less directly tied to traditional structural change forces.

### 3 Model and Equilibrium

Our analysis focuses on how features of intratemporal equilibrium allocations are affected by changes in the economic environment over time that operate through changes in income and relative prices. In order to capture these interactions in a simple a setting as possible, our benchmark model is static. In this section, we describe the economy and its equilibrium at a point in time; later we describe the features that we will allow to change over time to generate skill-biased structural change as described in the previous section. Our model is essentially a two-sector version of a standard structural transformation model extended to allow for two labor inputs that are distinguished by skill.

#### 3.1 Model

There are two types of households in the economy, distinguished by their skill level. We will refer to them as low skilled and high skilled, denoted by the subscript  $L$  and  $H$  respectively. The total mass of households is normalized to one and we denote the fractions of low and high skill households as  $f_L$  and  $f_H$  respectively, where  $f_L + f_H = 1$ . There are multiple sectors in the economy, distinguished by the extent to which they rely on low versus high-skilled labor. To facilitate the analysis we assume that there are only two sectors, which in the calibration of the model will be connected to the low and high-skilled aggregates studied in the previous section. As a practical matter, most high-skilled sectors

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<sup>11</sup>Katz and Murphy (1992) give a detailed analysis across 150 2-digit industry-occupation cells for the period, 1963-1987. Autor and Dorn (2013) present a recent account focusing on detailed occupation categories.

are services and most goods sectors are low-skilled sectors. For this reason it will be convenient to label the two sectors as goods and services even though these labels are not strictly correct. This will allow us to avoid having double indices to distinguish between both low- vs. high-skilled workers and low vs. high skill-intensive sectors.

All households have identical preferences over goods and services, independently of their skill level. We assume these preferences take the form:

$$a_G c_{Gi}^\varepsilon + (1 - a_G) (c_{Si} + \bar{c}_S)^\varepsilon$$

where  $c_{Gi}$  and  $c_{Si}$  are consumption of goods and services by an individual of skill level  $i$ ,  $0 < a_G < 1$ ,  $\bar{c}_S \geq 0$  and  $\varepsilon < 1$ . Note that if  $\bar{c}_S > 0$ , preferences are non-homothetic and, holding prices constant, the expenditure share on services will be increasing in income.<sup>12</sup> This non-homotheticity will be important in allowing the model to match the observation from the previous section concerning development and the value-added share for high-skilled sectors. Note that households are assumed to not value leisure, since our focus will be on the relative prices of labor given observed supplies.

Each of the two production sectors has a constant returns to scale production function that uses low- and high-skilled labor as inputs. We assume that each of these production functions is CES:

$$Y_j = A_j [\alpha_j L_j^\rho + (1 - \alpha_j) H_j^\rho]^{1/\rho} \quad j = G, S$$

where  $L_j$  and  $H_j$  are inputs of low- and high-skilled labor in sector  $j$ , respectively. The parameter  $\alpha_j$  will dictate the importance of low- versus high-skilled labor in each sector. While one could imagine that the elasticity of substitution between these two factors also differs across sectors, our analysis will assume that this value is the same for both sectors.

### 3.2 Equilibrium

We focus on a competitive equilibrium for the above economy. The competitive equilibrium will feature four markets: two factor markets (low- and high-skilled labor), and two output markets (goods and services), with prices denoted as  $w_L$ ,  $w_H$ ,  $p_G$  and  $p_S$ . We will later normalize the price of low-skilled labor to unity so that the price of high-skilled labor will also represent the skill premium, though in our derivations it will be convenient to postpone implementing this normalization.

The definition of competitive equilibrium for this model is completely standard and straightforward, so here we will focus on characterizing the equilibrium. Individuals of skill  $i = L, H$  solve

$$\max_{c_{Gi}, c_{Si}} a_G c_{Gi}^\varepsilon + (1 - a_G) (c_{Si} + \bar{c}_S)^\varepsilon$$

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<sup>12</sup>This is a simple and common way to create differential income effects across the two consumption categories. One can also generate non-homothetic demands in other ways. For example, Hall and Jones (2007) generate an income elasticity for medical spending that exceeds unity through the implied demand for longevity.

subject to

$$p_G c_{G_i} + p_S c_{S_i} = w_i. \quad (1)$$

The first-order conditions associated with their problem are

$$a_G c_{G_i}^{\epsilon-1} = p_G \lambda_i \quad (2)$$

$$(1 - a_G) (c_{S_i} + \bar{c}_S)^{\epsilon-1} = p_S \lambda_i \quad (3)$$

Rearranging these two first order conditions and substituting into (1) yields:

$$c_{G_i} = \frac{w_i + p_S \bar{c}_S}{p_S \left( \frac{1-a_G}{a_G} \frac{p_G}{p_S} \right)^{\frac{1}{1-\epsilon}} + p_G}$$

and

$$c_{S_i} = \frac{\left( \frac{1-a_G}{a_G} \frac{p_G}{p_S} \right)^{\frac{1}{1-\epsilon}} w_i - p_G \bar{c}_S}{p_S \left( \frac{1-a_G}{a_G} \frac{p_G}{p_S} \right)^{\frac{1}{1-\epsilon}} + p_G}$$

Normalizing  $w_L$  to unity the aggregate expenditure share for services is then given by:

$$\frac{p_S [(1 - f_H) c_{SL} + f_H c_{SH}]}{1 - f_H + f_H w_H} = \frac{p_S \left( \frac{1-a_G}{a_G} \frac{p_G}{p_S} \right)^{\frac{1}{1-\epsilon}}}{p_S \left( \frac{1-a_G}{a_G} \frac{p_G}{p_S} \right)^{\frac{1}{1-\epsilon}} + p_G} - \frac{p_S}{1 - f_H + f_H w_H} \frac{p_G}{p_S \left( \frac{1-a_G}{a_G} \frac{p_G}{p_S} \right)^{\frac{1}{1-\epsilon}} + p_G} \bar{c}_S \quad (4)$$

The problem of the firm in sector  $j = G, S$  is

$$\max_{L_j, H_j} p_j A_j [\alpha_j L_j^\rho + (1 - \alpha_j) H_j^\rho]^{1/\rho} - L_j - w_H H_j$$

The first order conditions are

$$p_j A_j [\alpha_j L_j^\rho + (1 - \alpha_j) H_j^\rho]^{1/\rho-1} \alpha_j L_j^{\rho-1} = 1 \quad (5)$$

$$p_j A_j [\alpha_j L_j^\rho + (1 - \alpha_j) H_j^\rho]^{1/\rho-1} (1 - \alpha_j) H_j^{\rho-1} = w_H \quad (6)$$

Taking the ratio of (5) and (6) we obtain

$$\frac{H_j}{L_j} = \left( \frac{1 - \alpha_j}{\alpha_j} \frac{1}{w_H} \right)^{1/(1-\rho)} \quad (7)$$

Substituting (7) into (5) and rearranging delivers an equation for the price of sector  $j$  output in terms of the skill premium  $w_H$  :

$$\hat{p}_j(w_H) = \frac{1}{A_j} \left[ \alpha_j^{1/(1-\rho)} + \frac{(1 - \alpha_j)^{1/(1-\rho)}}{w_H^{\rho/(1-\rho)}} \right]^{-1/\rho+1} \quad (8)$$

The above expression implies that the search for equilibrium prices can be reduced to a single dimension: if we know the equilibrium wage rate for high-skilled labor then all of the remaining prices can be determined.

In what follows we derive an expression for the market-clearing condition for high-skilled labor that contains the single price  $w_H$ . Using (7), the production function of sector  $j$ , and (8), we obtain

$$L_j = \left[ \alpha_j \hat{p}_j(w_H) A_j \right]^{\frac{1}{1-\rho}} \frac{Y_j}{A_j}. \quad (9)$$

Similarly, we solve for the demands for high-skilled labor in sector  $j$  as a function of output of sector  $j$  and the wage for high-skilled labor:

$$H_j = \left[ \frac{(1 - \alpha_j) \hat{p}_j(w_H) A_j}{w_H} \right]^{\frac{1}{1-\rho}} \frac{Y_j}{A_j} \quad (10)$$

Using (10) and equilibrium in the goods market, the market-clearing condition for high-skilled labor yields a single equation in  $w_H$ :

$$\begin{aligned} & \left[ \frac{(1 - \alpha_S) \hat{p}_S(w_H) A_S}{w_H} \right]^{\frac{1}{1-\rho}} \frac{\sum_{i=L,H} f_i \hat{c}_{Si}(w_H)}{A_S} \\ & + \left[ \frac{(1 - \alpha_G) \hat{p}_G(w_H) A_G}{w_H} \right]^{\frac{1}{1-\rho}} \frac{\sum_{i=L,H} f_i \hat{c}_{Gi}(w_H)}{A_G} = f_H. \end{aligned} \quad (11)$$

where we have used  $\hat{c}_{ji}(w_H)$  to denote the demand for output of sector  $j$  by a household of skill level  $i$  when the high-skilled wage is  $w_H$  and prices are given by the functions  $\hat{p}_i(w_H)$  defined in (8).

## 4 Accounting for Growth and Structural Transformation

In this section we describe how the model of the previous section can be calibrated so as to account for growth, structural transformation, and the skill premium. To do this we will use the above model to explain equilibrium outcomes at two different points in time, that we denote as 0 and  $T$  for the initial and terminal periods respectively. We assume that there are two types of changes in the economic environment across these two periods. One is a change in the fraction of individuals that are high skill. The other is technological change. However, we will allow for technological change along several dimensions. In particular, we assume that technological change within each sector can be some combination of skill biased technological change and skill neutral technological change. Skill-biased technological change in sector  $j$  will be captured by changes in  $\alpha_j$ , whereas neutral technological change will be captured by changes in  $A_j$ . Additionally, the mix of these two types of technological change is allowed to

differ across the two sectors. Consistent with the existing literature on technological change and the skill premium, we do not allow the parameter  $\rho$  to change over time. We also do not allow for preferences to change over time.

In choosing our targets, we again focus on the EUKLEMS data from Section 2. For the U.S., the complete data are available for the years, 1977 to 2005, so those two end years become our targets for 0 and  $T$ .<sup>13</sup> These dates are convenient, since 1977 effectively marks a local minimum in the skill premium (see Acemoglu and Autor (2011) for earlier data), and it secularly increases after 1977. The data contain total compensation and total hours by industry, skill level ("low", "medium", and "high", which are effectively, secondary degree or less, some tertiary schooling, and four year college degree or more), gender, and age groupings (15-29, 30-49, and 50 and over). We combine the compensation of KLEMS categories of "low" and "medium" educated workers of all genders and ages into our classification of low-skilled, and all varieties of "high" into high-skilled, in order to calculate aggregate and goods and service sector-specific labor income shares, using the same sectoral classification as in Section 2. To compute the skill premium, we compute wages as the ratio of compensation to hours, and the skill premium as the ratio of college-educated ("high") to high school-educated ("low") prime-aged (i.e., aged 30-49) male wages. This premium rises from 1.37 in 1977 to 1.65 in 2005, quite similar to the 1.39 and 1.64 in Acemoglu and Autor (2011, Figure 1) based on CPS data. Finally, we infer  $f_H$ , using the identity that the ratio of labor compensation equals the product of the skill premium and the relative quantity of high- to low-skilled labor ( $f_H$  and  $f_L = 1 - f_H$ , respectively). In doing so, the implicit assumption is that relative wages between different low-skilled (high-skilled) demographic groups reflect relative efficiency units of low-skilled (high-skilled) labor.

In mapping the model to these targets, we proceed in two steps. In the first step, we describe a procedure that allows us to infer the changes in parameters that represent technical change given a value for  $\rho$ . In the second step, we describe how to infer values for the preference parameters.

We begin with the determination of technological change. First, we show that given a value for  $\rho$ , the four values of the  $\alpha_{jt}$  are pinned down by sectoral factor income shares and the skill premium,  $w_{Ht}$ . To see this, note that the share of sector  $j$  income going to low skill labor is

$$\begin{aligned} \theta_{Ljt} &= \frac{L_{jt}}{\hat{p}_j(w_{Ht})Y_{jt}} \\ &= \frac{\alpha_j^{1/(1-\rho)}}{\alpha_j^{1/(1-\rho)} + \frac{(1-\alpha_j)^{1/(1-\rho)}}{w_{Ht}^{\rho/(1-\rho)}}} \end{aligned}$$

Therefore, given  $\rho$ , the skill premium  $w_{Ht}$ , and data for  $\theta_{Ljt}$ , the value of the

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<sup>13</sup>The EUKLEMS value-added and price data line up quite closely with BEA data, but the consistent aggregation is not available prior to 1977. They are available through 2007, but labor compensation and hours data are only available through 2005.

$\alpha_{jt}$  are given by:

$$\alpha_{jt} = \frac{1}{1 + w_{Ht}^\rho \left( \frac{1 - \theta_{Ljt}}{\theta_{Ljt}} \right)^{1-\rho}}.$$

Next we turn to determining the values of the  $A_{jt}$ 's. Although there are four of these parameters, the two values in period 0 basically reflect a choice of units and so can be normalized, leaving only two parameters to be determined. We next derive a condition that determines the two  $A_{jT}$ 's up to a scale factor. As is well known in the literature, if we had Cobb-Douglas sectoral technologies with identical labor share parameters, then relative sectoral prices would simply be the inverse of relative sectoral TFPs. In this case, changes in relative prices would pin down changes in relative TFPs, and hence determine the values of the two  $A_{jT}$ 's up to a scale factor. This same relation holds more generally, and in particular would also apply if the sectoral production functions are CES with identical parameters. While this result does not apply to our setting because of sectoral heterogeneity in the  $\alpha_{jt}$ 's, there is still a close connection between relative sectoral prices and relative sectoral TFPs (i.e., the  $A_{jt}$ ), though the relation is somewhat more complex. In particular, using equation (8) for the two sectors we have:

$$\frac{A_{Gt}}{A_{St}} = \frac{p_{Gt}}{p_{St}} \left[ \frac{\alpha_{Gt}^{1/(1-\rho)} + \frac{(1-\alpha_{Gt})^{1/(1-\rho)}}{w_{Ht}^{\rho/(1-\rho)}}}{\alpha_{St}^{1/(1-\rho)} + \frac{(1-\alpha_{St})^{1/(1-\rho)}}{w_{Ht}^{\rho/(1-\rho)}}} \right]^{-1/\rho+1}. \quad (12)$$

As noted above, the initial values of the  $A_{jt}$  simply reflect a choice of units. We will normalize  $A_{S0}$  to equal one, and given the calibrated values for the  $\alpha_{j0}$  and the value of  $w_{H0}$ , we will choose  $A_{G0}$  so as to imply  $p_{G0}/p_{S0} = 1$ . In this case  $p_{GT}/p_{ST}$  can be easily identified with the change in the relative sectoral prices, and this value from the data will pin down the sectoral TFPs in period  $T$  up to a scale factor.

This scale factor will of course influence the overall growth rate of the economy between periods 0 and  $T$ , so we choose this scale factor to target the aggregate growth rate of output per worker. However, in order to compute aggregate output at a point in time (and thus also the growth rate in aggregate output) it is necessary to determine the sectoral distribution of output. The relations that we have imposed thus far guarantee that maximum profits will be zero in each sector but do not determine the scale of operation in either sector. Intuitively, the split of activity across sectors at given prices will be determined by the relative demands of households for the two sectoral outputs at those same prices. Below we will describe how preference parameters can be chosen to match the sectoral distribution of value added at both the initial and final date. For now we simply note that if we assume this split is the same as in the data, then given our previous steps we can compute the growth rate of output per worker as a function of the scale factor and hence use the growth rate in aggregate output to determine the scale factor.

To summarize, at this point, given a value for  $\rho$ , we have identified all of the technology parameters given values for  $f_{Lt}$  at  $t = 0, T$ ,  $\theta_{jt}$  for  $j = G, S$ ,  $t = 0, T$ , the change in  $p_S/p_G$  and the growth of total output per worker. For our benchmark analysis we set  $\rho = 0.30$ , which corresponds to the value used in Katz and Murphy (1992), and which is commonly used in the literature. Though this is a commonly used value in the literature, it is worth noting that previous estimates using an aggregate production function do not necessarily apply in our setting. For this reason we will also do sensitivity analysis with regard to  $\rho$  over a fairly wide interval, ranging from  $-0.30$  to  $0.60$ . Table 2 provides values for the inputs into the calibration procedure. Table 3 below shows the implied values for the technology parameters.

Table 2  
Values Used to Calibrate Technology Parameters

$f_{L0}$	$f_{LT}$	$w_{H0}$	$w_{HT}$	$\% \Delta \frac{p_S}{p_G}$	$\% \Delta Y$	$\theta_{G0}$	$\theta_{GT}$	$\theta_{S0}$	$\theta_{ST}$	$\frac{C_{S0}}{Y_0}$	$\frac{C_{ST}}{Y_T}$
.78	.64	1.37	1.64	62.0	70.0	0.82	0.66	0.46	0.34	0.29	0.44

Table 3  
Calibrated Technology Parameters ( $\rho = 0.3$ )

$\alpha_{G0}$	$\alpha_{S0}$	$\alpha_{GT}$	$\alpha_{ST}$	$A_{ST}/A_{S0}$	$A_{GT}/A_{G0}$
0.72	0.45	0.58	0.35	1.20	2.22

A few remarks are in order. Not surprising given the way in which we grouped industries into the two sectors, we see that the weight on low-skilled labor is greater in the goods sector than in the service sector at both dates. More interesting is that in both sectors technological change has an important component that is skill biased. While the level drop in  $\alpha$  is larger for the goods sector than the service sector, the percent changes are very similar, though slightly larger for the service sector than the goods sector (22% versus 20%). It follows that the extent to which technological change is skill biased is relatively similar for the two sectors. However, overall technological progress is much greater in the goods sector than in the service sector. The TFP term in the goods sector more than doubles over the nearly thirty year period from 1977 to 2005, corresponding to an average annual growth rate of 2.89%. In contrast, the growth of the TFP term in the service sector averages only 0.65% per year.

We now turn to the issue of determining the values for the three preference parameters:  $a_G$ ,  $\bar{c}_S$  and  $\varepsilon$ . While technological change can be inferred without specifying any of the preference parameters, we cannot evaluate some of the counterfactual exercises of interest without knowing how relative demands for the sectoral outputs are affected by changes in prices. As noted above, the calibration of technology parameters used information about sectoral expenditure shares without guaranteeing that observed expenditure shares were consistent with household demands given all of the prices. Requiring that the aggregate expenditure share for goods (or services) is consistent with the observed values in the data for the initial and terminal date would provide two restrictions on



the three preference parameters. It follows that we would either need to introduce an additional moment from the data, or perhaps use information from some outside study to determine one of the three preference parameters. For our benchmark results we will follow the second approach and fix the value of  $\varepsilon$ , and then use data on aggregate expenditure shares to pin down the values for  $a_G$  and  $\bar{c}_S$ . It will turn out that our main finding is relatively robust to variation over a large range of values of  $\varepsilon$ , thereby lessening the need to tightly determine its value. Nonetheless, in Section 5 we will describe how cross-sectional data on expenditure shares could be used as an additional moment and allow us to determine all three preference parameters.

The empirical literature does not provide estimates of  $\varepsilon$  that correspond to our definitions of the two sectors. However, as noted previously, what we label the goods sectors does contain almost all of the industries that produce goods, while the sector that we label as services does consist primarily of service sector industries in the actual economy. However, this split is not sharp, since low skilled service sector industries such as retail trade are also included in what we label the goods sector. Nonetheless, we believe that information about the elasticity of substitution between the “true” goods and services sectors should be informative about a reasonable range of values for  $\varepsilon$  in our model. Recalling that the objects in our utility function reflect the value-added components of sectoral output, the relevant estimates in the literature would include Herrendorf et al. (2013), Buera and Kaboski (2009), and Swiecki (2014). All of these studies suggest very low degrees of substitutability between true goods and true services. For this reason we consider values for  $\varepsilon$  in the set  $\{-7, -4, -1\}$ , with  $\varepsilon = -4$  chosen as our benchmark.

Simple manipulation of the household demands gives:

$$c_{St} = \frac{\left(\frac{p_{Gt}}{p_{St}}\right)^{\frac{\varepsilon}{1-\varepsilon}} \left(\frac{1-a_G}{a_G}\right)^{\frac{1}{1-\varepsilon}}}{\left(\frac{p_{Gt}}{p_{St}}\right)^{\frac{\varepsilon}{1-\varepsilon}} \left(\frac{1-a_G}{a_G}\right)^{\frac{1}{1-\varepsilon}} + 1} - \frac{1}{\left(\frac{p_{Gt}}{p_{St}}\right)^{\frac{\varepsilon}{1-\varepsilon}} \left(\frac{1-a_G}{a_G}\right)^{\frac{1}{1-\varepsilon}} + 1} \frac{p_{St}\bar{c}_S}{1 - f_t^H + f_t^H w_t}$$

for total demand for services in period  $t$ . Using information on relative prices and total income, given a value for  $\varepsilon$  this allows us to determine values for  $a_G$  and  $\bar{c}_S$ .

Table 4 shows the values for the preference parameters in the different scenarios.

	$\varepsilon$	$a_G$	$\bar{c}_S$
Benchmark	-4.0	0.71	0.14
Low $\varepsilon$	-7.0	0.30	0.37
High $\varepsilon$	-1.0	0.92	0.11

The qualitative patterns in this table are intuitive. In all cases the change in income, relative prices and the aggregate expenditure shares are all the same.

As we move from  $\varepsilon = -4.0$  to  $\varepsilon = -7.0$  we decrease the elasticity of substitution between the two goods, implying a smaller response in relative quantities but a larger response in relative expenditure shares. In order to compensate for this larger effect, we need to decrease the impact of income changes on relative expenditure shares, implying a lower value for  $\bar{c}_S$ . The lower value for  $\bar{c}_S$  will in turn lead to a higher expenditure share on services in the initial period, since the non-homotheticity is now less important. Hence, in order to match the expenditure shares for the initial period we need to attach a lower weight to consumption of goods. As we move from  $\varepsilon = -4.0$  to  $\varepsilon = -1.0$  we see the reverse pattern.

## 5 Decomposing Changes in the Skill Premium

Having calibrated the model so as to be consistent with growth, structural transformation, changes in the skill premium and changes in the share of skilled labor, we can now use the model to perform counterfactuals that allow us to attribute changes in the skill premium to changes in various aspects of the economic environment. Our primary objective is to decompose the effect of changes in technology on the skill premium into a piece due to skill biased technological change and a residual piece that is due to other forms of technological change. The residual piece affects the relative demand for skilled individuals indirectly, through its impact on the relative consumption of services.

In order to decompose the effects of technological change into these subcomponents we carry out several counterfactuals, which we report in Table 5, for each of the three specifications that differ with respect to the value of  $\varepsilon$ .

Table 5  
Decomposing Changes in the Skill Premium

	$\varepsilon = -1.0$	$\varepsilon = -4.0$	$\varepsilon = -7.0$
$w_{H0}$ Data	1.37	1.37	1.37
$w_{H0}$ Model	1.37	1.37	1.37
$w_{HT}$ Data	1.65	1.65	1.65
$w_{HT}$ Model	1.65	1.65	1.65
$w_{HT}$ Model—changes in $f_i$ only	0.85	0.82	0.81
$w_{HT}$ Model—changes in $f_i$ and $A_j$ only	1.04	1.04	1.03
$w_{HT}$ Model—changes in $f_i$ and $\alpha_j$ only	1.41	1.38	1.38

The first four rows of the table simply report that in the data, the skill premium increased from 1.37 to 1.65 between 1977 and 2005, and that our calibrated model perfectly replicates this change. The rest of the table decomposes this change in the model by considering several counterfactuals. The first counterfactual assesses the role of “supply” versus “demand” factors. Specifically, the share of labor supply coming from skilled workers increases between 1977 and 2005, and in the absence of any other changes exerts downward pressure on the skill premium. The fifth row of Table 5 shows that if the change in relative supply of skill had been the only change over time, it would have resulted in a drop

in the skill premium of between 52 and 56 percentage points across the three specifications. Given that we in fact observe a increase in the skill premium of 28 percentage points, it follows that the overall effect of technological change is to increase the skill premium by between 80 and 84 percent.

Our next goal is to decompose the overall effect of technological change into the part that is due to skill biased technological change (i.e., changes in the  $\alpha_{jt}$ 's) and a residual due to other dimensions of technical change (i.e., the  $A_{jt}$ 's). Before doing so it is of interest to note that in standard aggregate analyses of technological change, it is only skill biased technological change that affects the skill premium, since changes in TFP have no impact on relative marginal products holding factor supplies constant. Central to our analysis is the fact that this result does not hold in our model. The reason that this is true is precisely because the two sectors have different skill intensities. As a result, any change in the economic environment that leads to changes in the composition of demand will impact on the relative demand for skill. As is standard in the structural transformation literature, our model features two forces through which changes in the  $A_{jt}$ 's can influence the sectoral composition of output. One is through income effects: because of nonhomothetic preferences, any change in technology that increases income will lead to a reallocation of activity from the goods to the services sector, thereby indirectly increasing the relative demand for skill. The other is through relative price effects. If goods and services have an elasticity of substitution that is less than unity, then decreases in the relative productivity of services will also lead to a reallocation of factors of production to the service sector, again indirectly increasing the relative demand for skill.

There are two natural exercises that one could perform to assess the contribution of changes in the  $A_{jt}$ 's to changes in the skill premium. In the first we shut down the changes in the  $\alpha_{jt}$ 's and compute what fraction of the overall increase is accounted for by changes in the  $A_{jt}$ 's alone. In the second we shut down changes in the  $A_{jt}$ 's and find the residual that is not accounted for by changes in the  $\alpha_{jt}$ 's. In a linear model these two exercises would give the same answer, but to the extent that nonlinearities are present they may differ. It will turn out that the answers do differ, but only to a minor extent. The final two rows in Table 5 present the results of these two counterfactuals. For concreteness, we first focus on the case of  $\varepsilon = -4.0$ . When we hold the  $\alpha_{jt}$ 's fixed, we find that the change in the  $A_{jt}$ 's accounts for 22 percentage points of the overall 83 percentage point increase accounted for technical change, or approximately 27%. If we instead fix the  $A_{jt}$ 's, the residual is 27 percentage points, which represents approximately 33% of the total. Based on this we conclude that non-skill biased technical change accounts for around 30% of the overall change in the skill premium due to technical change. Put somewhat differently, according to our calibrated model, if skill biased technical change had been the only force affecting the relative demand for skill then the skill premium would have effectively stayed the same over the period 1977 to 2005 instead of increasing by 28 percentage points.

If we redo this calculation for the other two values of  $\varepsilon$  the answers are very similar. For  $\varepsilon = -1.0$  the two methods imply that changes in the  $A_{jt}$ 's account

for 24% and 30% of the overall change in the skill premium due to technical change, whereas for  $\varepsilon = -7.0$  the two values are 26% and 32%. From this we conclude that our finding of significant contribution of changes in the  $A_{jt}$ 's is robust to a large variation in the value of  $\varepsilon$ .

In the introduction we stressed the fact that aggregate production function analyses abstract from compositional changes, and that our main objective was to assess the quantitative importance of the compositional changes that are associated with the process of structural transformation during development. In order to illustrate that this is the mechanism that we are picking up in the above calculations it is of interest to examine the relationship between the different changes in the economic environment and the sectoral composition of value added. Table 6 reports the results for each of the three values of  $\varepsilon$ .

Table 6  
Technical Change and Value Added Share of Services

	$\varepsilon = -1.0$	$\varepsilon = -4.0$	$\varepsilon = -7.0$
US Data 1977	0.29	0.29	0.29
Model 1977	0.29	0.29	0.29
US Data 2005	0.44	0.44	0.44
Model 2005	0.44	0.44	0.44
Model with fixed $A_j$	0.27	0.25	0.25
Model with fixed $\alpha_j$	0.46	0.46	0.45

The first four rows of the table simply confirm that the service sector grew significantly between 1977 and 2005, increasing its share of value added from 29 percent to 44 percent, and that our calibrated model perfectly accounts for this change. The last two rows provide two different ways of assessing the role of changes in the  $A_j$ 's and the  $\alpha_j$ 's in accounting for this compositional change. Both methods provide the same simple message: virtually all of the compositional change is accounted for by changes in the sectoral TFPs. It follows that our previous decomposition of changes in the skill premium due to the two different sources of technical change can effectively be interpreted as statements about the importance of compositional changes.

Non-skill biased technological change in our model still has two dimensions: one of which increases the overall level of TFP in the economy and the other of which led to higher relative TFP in the goods sector. As we noted above, both of these changes tend to reallocate activity from the goods sector to the service sector, thereby indirectly increasing the relative demand for skill. It is perhaps of interest to examine the relative magnitude of these two effects. Note that for given changes in the  $A_{jt}$ 's the relative magnitude of these two effects is dictated by the preference parameters  $\varepsilon$  and  $\bar{c}_s$ : as  $\varepsilon$  becomes more negative relative TFP changes have larger effects, and as  $\bar{c}_s$  becomes larger then sector neutral changes in the  $A_{jt}$ 's have larger effects. Because our calibration procedure implies that as  $\varepsilon$  becomes more negative the value of  $\bar{c}_s$  decreases, we expect to find that sector neutral change plays a larger role for smaller values of  $\varepsilon$ . To evaluate this we consider the counterfactual in which we hold all parameters

fixed from the original calibration, allow the  $f_{it}$ 's and the  $\alpha_{jt}$ 's to change as before, but counterfactually force the  $A_{jt}$ 's to grow at the same rate so as to yield the same overall change in aggregate output as in the data. When we do this, the implied values of the skill premium are 1.16, 1.08, and 1.07 for the cases of  $\varepsilon = -1.0$ ,  $-4.0$ , and  $-7.0$  respectively. It follows that when  $\varepsilon = -1.0$  it is income effects that dominate the overall impact of the  $A_{jt}$ 's on the skill premium, whereas for the more negative values of  $\varepsilon$  the sector biased nature of TFP growth is somewhat more important than the income effect. So while the three different specifications offer very similar decompositions regarding the overall effect of changes in the  $A_{jt}$ 's, they do have different implications for what type of changes in the  $A_{jt}$  will lead to future changes in the skill premium.

## 5.1 Sensitivity to $\rho$

For the results in the previous section we assumed that  $\rho = 0.30$ , which we noted was a standard value in the literature, and the value implied by the analysis in Katz and Murphy (1992). However, we also noted that the aggregate analyses that have supported this estimate are not necessarily appropriate in our multi-sector economy. For this reason we also consider a wider range of values for  $\rho$  to assess the extent to which the above conclusions are robust to variation in this parameter.

We consider two alternative values of  $\rho$ , corresponding to higher and lower elasticities of substitution. Specifically, we consider  $\rho = -0.30$  and  $\rho = 0.60$ . In each case we redo the calibration procedure as before. While the value of  $\rho$  does affect the quantitative findings, it leaves our main message largely unchanged. For example, focusing on the case of  $\varepsilon = -4.0$  we find that when  $\rho = -.30$ , the share of changes in the skill premium due to technical change that are accounted for by changes in the  $A_{jt}$  is 28% and 43% from the two methods. When  $\rho = 0.60$  the corresponding values are 22% and 24%. We conclude that our main finding of a significant role for changes in demand composition induced by technical change in accounting for changes in the skill premium is robust to considering a wide range of values for  $\rho$ .

## 5.2 Using Data to Infer $\varepsilon$

In the results above we considered a range of values for  $\varepsilon$  rather than trying to use our model to infer a specific value. Since our main message was robust to a wide range of values for  $\varepsilon$  we do not view this as a particular limitation of the analysis. Nonetheless, in this subsection we describe how the use of a cross-sectional moment on the household side would allow us to also infer a value for  $\varepsilon$ . One way to frame the issue is the following. The expenditure shares at time 0 effectively pins down the weight on goods in the utility function. Our calibration procedure requires that changes in aggregate expenditure shares be consistent with observed changes in income and relative prices. However, all this does is restrict us to a one parameter family of combinations of income effects and substitution effects, i.e., there is a one parameter family of pairs  $(\varepsilon, \bar{c}_S)$

that can deliver the required change in expenditure shares for given changes in income and relative prices. In order to uniquely pin down the parameter pair we would need an additional moment that reveals information about the size of these two effects.

Intuitively, cross-sectional information can provide information about the magnitude of the income effect: assuming that all households have the same preferences and face the same prices at a point in time, cross-sectional heterogeneity in income will allow us to infer the size of the income effect. This can be implemented using the cross-sectional information that we reported in Section 2. In particular, our empirical analysis found that the expenditure share for services is 0.04 higher for high skill households than for low skill households. If we require that our model match this moment in the final time period, the implied values for  $\varepsilon$  and  $\bar{c}_S$  are  $-7.7$  and  $0.11$  respectively when we assume  $\rho = .30$ . This would correspond to values of  $\varepsilon$  around the lower end of the interval that we considered. As a practical matter, it turns out that moving to increasingly negative values of  $\varepsilon$  even from  $\varepsilon = -4.0$  has relatively small effects, as could already be seen in Table 4. We have also repeated this exercise for alternative values of  $\rho$  and obtained estimates of  $\varepsilon = -5.7$  and  $-13.1$  for  $\rho$  equal to  $-0.30$  and  $0.60$  respectively. While we do not report the results for these cases in detail, we note that our main message remains unaffected if we were to adopt these specifications.

Having offered the idea of using cross-sectional data to infer the size of income effects on the demand for what we have labelled goods and services, we think it is important to repeat one important limitation of this approach in the current context. Two of the largest components of high skill services are education and health care, both of which are not well tracked by household expenditure surveys. To the extent that spending on some components of education reflect a collective choice, it is not clear that cross-sectional data will be useful in detecting how cross-sectional differences in income affect desired consumption.

## 6 Conclusion

Using a broad panel of advanced economies, we have documented a systematic tendency for development to be associated with a shift in value added to high-skill intensive sectors. It follows that development is associated with an increase in the relative demand for high skill workers. We coined the term skill-biased structural change to describe this process. We have built a simple two-sector model of structural transformation and calibrated it to US data over the period 1977 to 2005 in order to assess the quantitative importance of this mechanism for understanding the large increase in the skill premium during this period. We find that technological change overall increased the skill premium by slightly more than 80 percentage points, and that roughly 25 of these percentage points (or about 30% of the overall change) is due to technological change which operated through compositional changes.

In order to best articulate the mechanism of skill-biased structural change we have purposefully focused on a simple two-sector model. As we noted in Section 2, there is good reason to think that the mechanism we have highlighted is also at work at a more disaggregated level, so it is of interest to explore this mechanism in a richer model. The literature has also emphasized the possibility that increases in trade might lead to changes in the composition of valued added across sectors. Katz and Murphy (1992) specifically noted this possibility, and more recent analyses include Feenstra and Hanson (1999) and Autor et al. (2013). We think it is important to note that the compositional effects that we have focused on in this paper are not likely to be reflecting changes due to trade. The reason for this is that our high-skill intensive sector is composed entirely of industries from the service sector. It is plausible that part of what we identified as within sector skill biased technical change may at least in part reflect compositional effects due to trade, to the extent that trade had caused manufacturing activity in the US to shift to more skill intensive industries.

Our quantitative analysis focused on the US. Since we found that the phenomenon of skill-biased structural change is common to all of the advanced economies for which EUKLEMS had the available data, it will also be of interest to repeat our analysis for these other countries as well.

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