

Trade Liberalization, Structural Change, and Skill Premium Growth in India

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Abstract

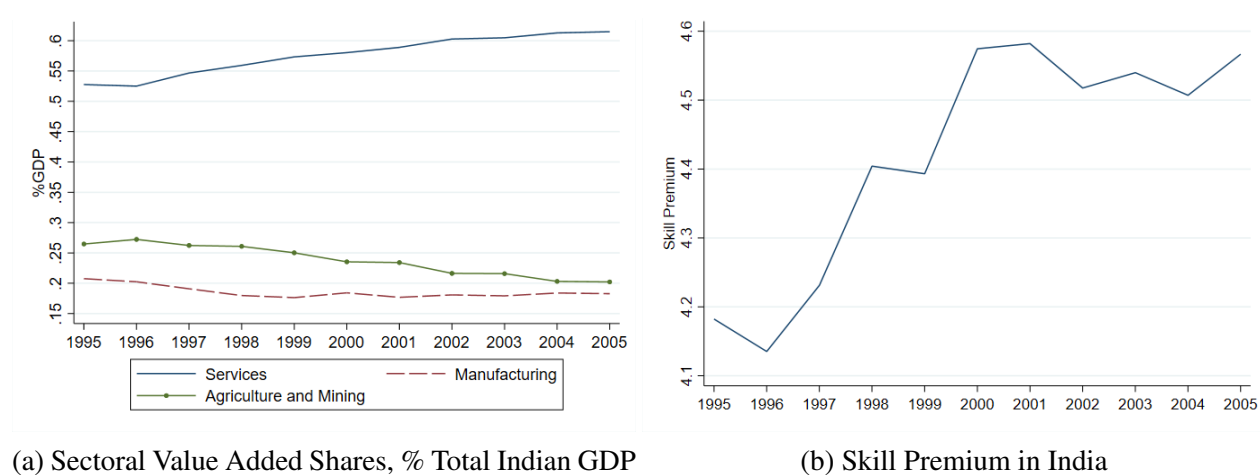
This paper examines the impact of changing trade costs on structural change and skill premium growth in India from 1995-2005. I build a model featuring asymmetric trade costs, multistage production, tradable services, tariffs, and two types of labor, skilled and unskilled. In my model, service export cost reductions bolster India's comparative advantage in services while goods import cost reductions increase the domestic expenditure share on services through a relative price effect. Both of these channels drive growth in the value added share of services and the skill premium, and multistage production contributes to these outcomes through an amplified elasticity of relative wages to changes in trade costs. I calibrate the model for three countries in the baseline year, then simulate trade cost reductions over time. I find that changing trade costs, including both tariffs and icebergs, explain 46% of India's service sector growth, 56% of its manufacturing sector decline, 41% of its agricultural decline, and 74% of its skill premium growth from 1995-2005. Further, I find that reductions in consumer goods tariffs increase the skill premium in India, whereas producer goods tariff reductions decrease the skill premium. Finally, I show that the inclusion of two stages of production is quantitatively important in explaining structural change and skill premium growth in India, and allows for the flexibility needed to match important moments during calibration that cannot be matched in a one-stage model.

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1 Introduction

For many developing and advanced economies, the 1990s and 2000s marked an era of robust service sector growth and progress toward trade liberalization. Among the countries experiencing these two concurrent trends, India's experience stands among the most stark and significant in shaping the structure of the world economy. During the period 1995-2005, India's share of world GDP grew from 1.48% to 1.94%, making its expansion the second largest in the world over this time frame, trailing only China.¹ Service sector growth drove this rapid economic expansion, with India's service sector value added as a share of total GDP rising from 52.8% to 61.5% from 1995 to 2005. As can be seen in Figure 1a, value added shares fell for both manufacturing and agriculture as India's service sector grew. Within the service sector, the fastest growing industries were skilled services, including communication services, financial services, and business services (Gordan and Gupta, 2005). The growth of India's skilled service production during this period was associated with a rise in the return to skilled labor, with the relative wage of college-educated labor increasing 9.2% (see Figure 1b).²

Figure 1: Structural Change and Rising Skill Premium in India, 1995-2005



Source(s): WIOD

¹World Bank national accounts data, and OECD National Accounts data files

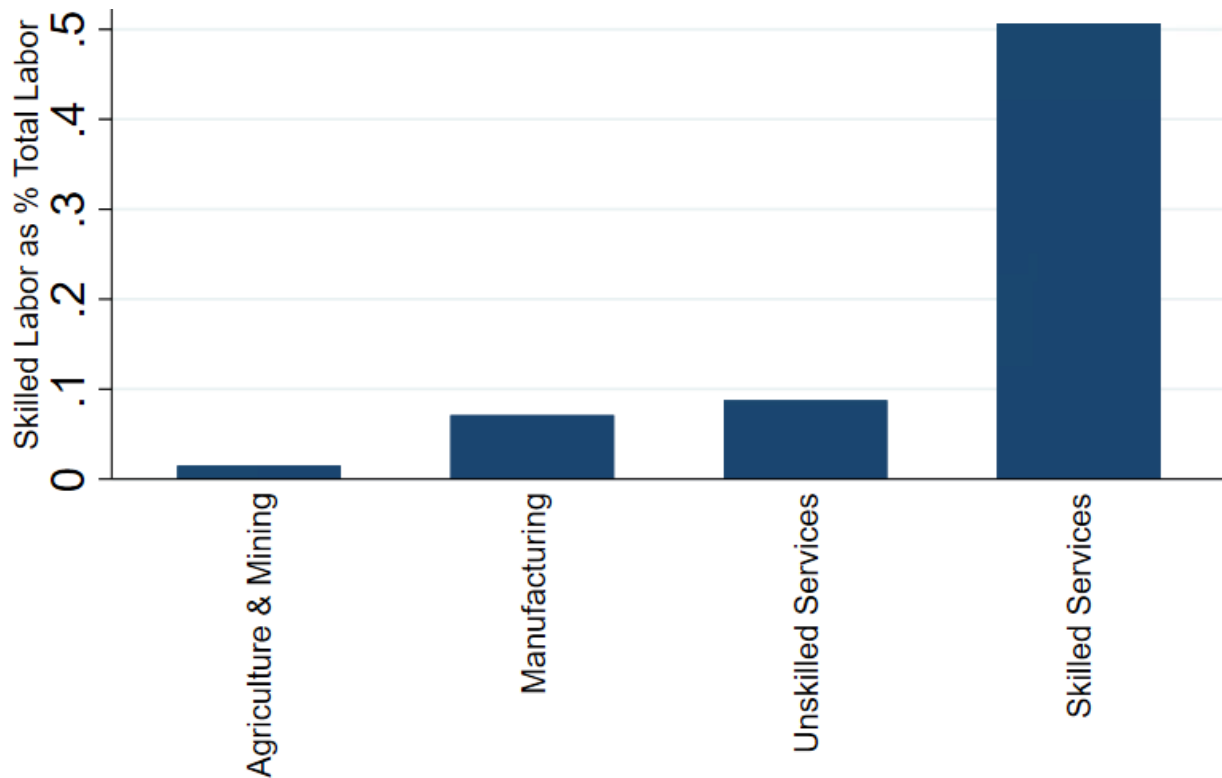
²Skill premium is calculated as the ratio of the average wage of college-educated labor to the average wage of all other labor.

The purpose of this paper is to examine structural change and skill premium growth in India, through the lens of a quantitative trade model featuring asymmetric trade costs, multistage production, tradable services, tariffs, and two types of labor (skilled and unskilled). I argue that changes in trade costs can explain about half of India's service sector growth and manufacturing sector decline, and almost three-fourths of India's skill premium growth over the period 1995-2005. This result is driven primarily by reductions in service export costs and goods import costs, with the decline in goods import costs occurring mostly through tariff reductions.

In my model, similarly to Lee (2023), trade costs are calibrated to be asymmetric between countries, meaning that import costs differ from export costs for any given country. India's changing sectoral composition occurs in my model through changes in these trade costs, which differentially affect the demand for Indian production of goods and services through three different channels. First, reductions in the relative price of final goods, driven in part by tariff reductions, increases the relative expenditure share on final services for the representative domestic consumer, ultimately resulting in an increase in Indian service production. This occurs because each country's representative consumer has constant elasticity of substitution (CES) preferences, with a non-unitary elasticity of substitution between sectors such that goods and services are complements.

Similarly, reductions in the relative price of intermediate goods drives an increase in the relative expenditure share on intermediate services for domestic producers. This mechanism occurs through the composite intermediate input used by producers, which is also modeled as a CES aggregator of output from all sectors with a non-unitary elasticity of substitution between sectors. Finally, foreign demand increases for Indian exports of services in response to reductions in service export costs, and this effect is potentially amplified by concurrent structural change occurring within India's trading partners. A rise in India's skill premium occurs because the production of services is on average more skilled labor-intensive than the production of goods (see Figure 2), and hence the relative return to skilled labor grows as India's service sector grows. Each of these mechanisms are amplified by the multi-stage production structure, as the elasticity of relative wages and trade flows to changes in trade costs is greater in a two-stage model than in a one-stage model.

Figure 2: Skilled Labor Intensity by Sector in India, 1995-2005

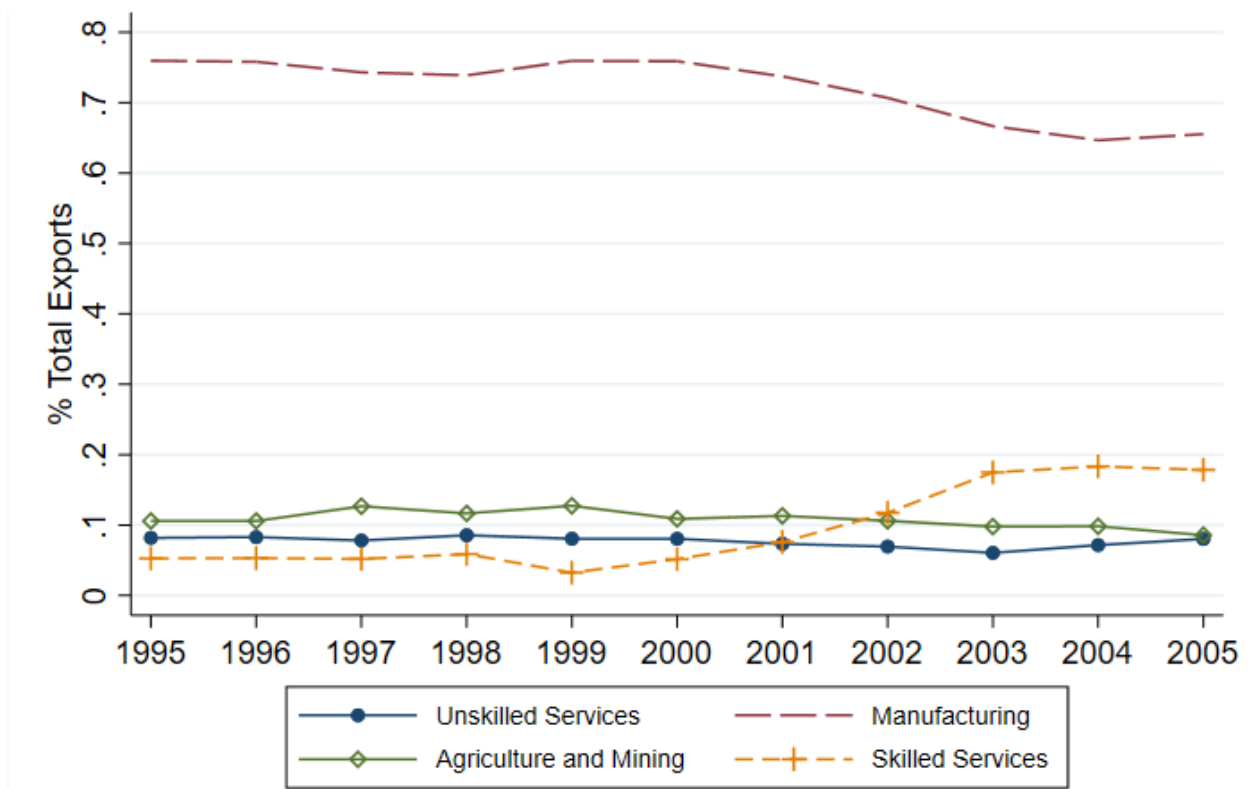


Source(s): WIOD

Regarding service export cost reductions, many previous studies have assumed services to be non-traded, whereas a recent literature has recognized the fact that trade in services accounts for a large and growing share of international trade flows. The time frame of my analysis, 1995-2005, captures the start of the period in which many services, and skilled services in particular, became dramatically less costly to trade across long distances due to the rapid growth and increased usage of the internet and modern information communication technology (ICT). These developments made it possible to trade services that were previously considered to be non-traded (Goswami et al., 2012). India benefited immensely from the increased ease of trading skilled services, and as a result saw its skilled service exports as a share of total Indian exports grow from 5.2% to 17.8% (see Figure 3). Overall, India's share of world service exports grew from 0.5% to 2% from 1995 to 2005.³

³For comparison, India's share of world goods exports only grew from 0.6% to 1.0% from 1995-2005 (Source: WIOD).

Figure 3: Sectoral Exports as Percentage of Total Indian Exports, 1995-2005

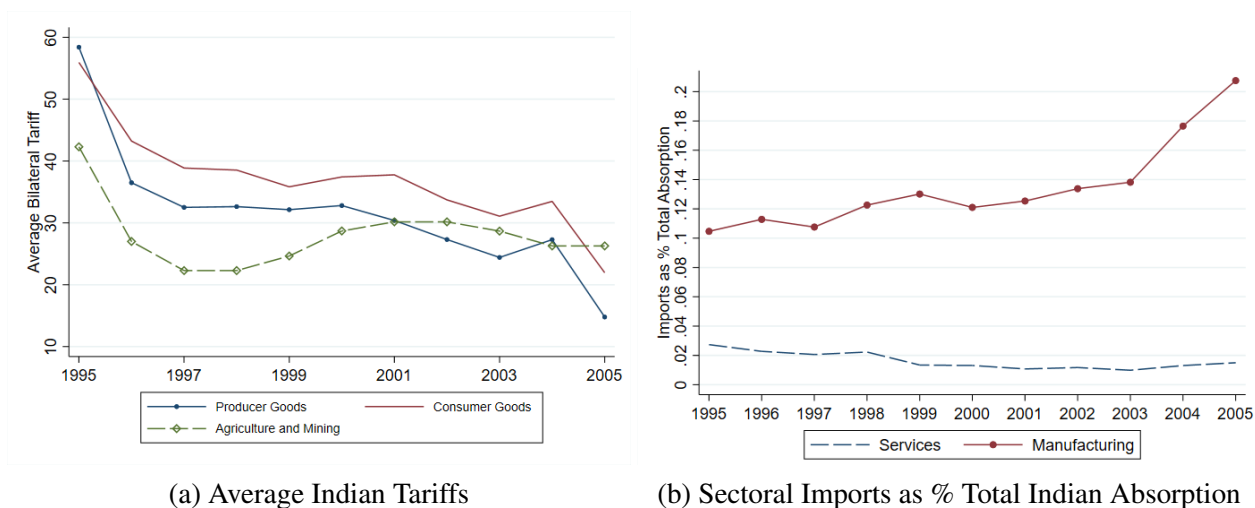


Source(s): WIOD

Meanwhile, declining goods import costs in the form of tariff reductions drove much of India's declining manufacturing value added share over the same time period. In the 1990s and 2000s, India underwent a significant trade liberalization effort in which tariffs were lowered on intermediate and final goods alike. This effort was initiated by a Stand-By Arrangement made with the International Monetary Fund (IMF) in 1991, which was made conditional on a structural adjustment program that included trade liberalization as a key component (Topalova and Khandelwal, 2010). As can be seen in Figure 4a, from 1995 to 2005 the average tariff applied by India dropped from 57% to 22% for imports of manufactured consumer goods, from 57% to 15% for imports of manufactured producer goods, and from 42% to 26% for imports of agricultural and mining goods. Figure 4b shows that during this time frame, manufacturing imports as a percentage of total Indian absorption doubled, whereas service imports as a percentage of total absorption decreased

slightly.⁴

Figure 4: Tariff Reductions and Imports by Sector in India, 1995-2005



Source(s): WIOD, World Bank World Integrated Trade Solution (WITS) database

My model is calibrated for three countries: India, the U.S., and a rest of the world (ROW) aggregate. The model is initially calibrated to match moments in the data in the baseline year, 1995. I then calibrate a full sequence of trade costs from 1995-2005, structurally backing these parameters out from gross output price data and the tables found in the World Input-Output Database (WIOD). I also show that an equivalence exists between trade costs that are backed out using relationships implied by my two-stage model and a one-stage model, such as that used by Lee (2023).

I then perform a series of counterfactual analyses to quantify impact of changing trade costs on structural change and skill premium growth in India from 1995 to 2005. In my first counterfactual exercise, I let calibrated trade costs change while fixing all other parameters to isolate the role of trade costs in explaining India's structural change and skill premium growth over time. I find that changing trade costs, including both tariffs and icebergs, explain 46% of India's service sector growth, 56% of India's manufacturing sector decline, 41% of its agricultural decline, and 74% of its skill premium growth over the period 1995-2005. I then isolate the respective roles of changing iceberg trade costs and tariffs to decompose the overall impact of changing trade costs into two

⁴Total absorption is calculated as gross production plus imports, minus exports.

channels. I find that changes in iceberg trade costs are quantitatively more important in explaining India's service sector growth, agriculture sector decline, and skill premium growth, whereas tariff reductions are more important in explaining India's manufacturing sector decline.

Further, I assess the differential impact of tariffs by sector, comparing producer goods tariff reductions to consumer goods tariff reductions. Notably, reductions in consumer goods tariffs are found to increase the skill premium in India, whereas producer goods tariff reductions decrease the skill premium. The reason underlying this finding is that producer goods are more unskilled labor-intensive than both consumer goods and unskilled services in India. Therefore, tariff reductions and a corresponding contraction of India's producer goods sector will reallocate value added toward more unskilled-intensive sectors, increasing the return to unskilled labor and reducing the skill premium. Finally, I recalibrate my model in the case of only one stage of production and run the same counterfactual exercises described above, showing that the inclusion of multiple stages of production is quantitatively important in explaining structural change and skill premium growth in India, and allows for the flexibility needed to calibrate the model in a way that accurately characterizes country-level gross output shares.

1.1 Related Literature

This paper connects three strands of literature. The primary strand that relates to my paper is that studying structural change in open economies. Early examples of this literature include Matsuyama (2009) and Uy, Yi, and Zhang (2013). More recently, and focusing on the U.S. in particular, Kehoe, Ruhl, and Steinberg (2017) find that trade plays a small role in explaining structural change, and that growth in manufacturing productivity was the primary cause. The results of my paper are consistent with this finding for the U.S., as I find that changes in trade costs do not explain a quantitatively significant amount of structural change in the U.S.⁵

⁵Similarly, Swiecki (2017) finds differential productivity growth rather than changing trade costs to be the primary driver of structural change for most countries, including India, using a broader sample. While this finding is not consistent with the findings documented in my paper, my model is better suited to explain India's structural change, as I assume services to be traded while Swiecki (2017) does not, and service exports accounted for about 30% of Indian service sector growth from 1995-2005.

The two papers most similar to mine within this strand of literature are Lee (2023) and Cravino and Sotelo (2019).⁶ Lee (2023) shows the importance of tradable services and asymmetric trade costs in explaining structural change, finding the impact of globalization on structural change to be heterogeneous across countries from 1995 to 2018. Cravino and Sotelo (2019) utilize a one-stage quantitative trade model featuring skilled and unskilled labor, finding reductions in trade costs to have a negative impact on manufacturing employment and the relative wage of unskilled workers. I complement these studies by focusing on one particular case of trade liberalization, allowing me to assess the extent to which Indian policy directly affected the pace of structural change. This paper is to my knowledge the first to introduce tariffs into a model of trade and structural change. Additionally, this paper is the first to introduce multi-stage production into a model of trade and structural change.

The second strand of literature closely relating to this paper studies international trade and its role in explaining skill premium growth. The experience of many countries from the 1990s onward differs from predictions that would be made from a traditional Heckscher-Ohlin model, which predicts that when trade barriers fall between advanced and developing economies, the relative wage of unskilled labor will increase in developing economies, which are typically unskilled labor-abundant, whereas the relative wage of skilled labor will increase in advanced economies, which are skilled labor-abundant. However, the observed experience of the 1990s and 2000s is that trade barriers fell while skill premium growth grew for advanced and developing economies alike. A recent literature has emerged attempting to explain this phenomenon. Cravino and Sotelo (2019) and Burstein and Vogel (2017) are recent examples within this literature.⁷ Lee (2020) and Lee and Yi (2018) are also recent examples, studying the skill premium implications of declining trade costs in the presence of worker-level comparative advantage across sectors and occupations. My study focuses on the roles of trade policy and changing trade costs in explaining skill premium growth in the specific case of India, which stands out as one of the most stark examples of a developing,

⁶Also related is Sposi, Yi, and Zhang (2021) show how sectoral trade integration and sector-biased productivity growth interact to cause structural change.

⁷Other examples include Parro (2013) and Burstein, Cravino, and Vogel (2013), who look at the effects of capital imports on skill premium growth using models featuring capital-skill complementarity.

unskilled labor-abundant economy experiencing skill premium growth after opening up to trade.

Finally, my study draws heavily from the literature embedding multiple stages of production into quantitative models of trade. Yi (2003) demonstrates that vertical specialization across two stages of production magnifies the effects of tariff reductions relative to models featuring one stage of production. Antras and de Gortari (2020) build a model which restores the tractability of the model introduced by Eaton and Kortum (2002) in the case of multi-stage production, generalized to tractably accommodate many stages and countries. Recently, numerous studies have extended this framework in various contexts.⁸ The study within this category that connects most closely with mine is with Zhou (2023), who incorporates tariffs and multiple sectors into the multi-stage framework put forth by Antras and de Gortari (2020) to assess the welfare implications of the U.S.-China trade war.⁹ While the focus of Zhou (2023) is the welfare implications of tariff reductions, my study focuses on the role of tariff reductions in explaining structural change and skill premium growth.

My study complements Zhou (2023) and Antras and de Gortari (2020) by incorporating two types of labor, skilled and unskilled, and by considering asymmetric trade costs. As is argued by Waugh (2010), it is important to model trade costs as asymmetric when considering trade between developing and advanced economies, as advanced economies typically experience lower export costs than developing economies. Lee (2023) extends this argument to the structural change literature by arguing that trade cost asymmetry in services exists, and that the evolution of asymmetric changes in trade costs is important in explaining the impact of globalization on structural change. My study is also similar to Connolly and Yi (2015), who assess the impact of tariff reductions and trade policy reforms on per capita GDP growth in South Korea, in a quantitative trade model featuring two-stage production and tariffs. The focus of my paper is different, as Connolly and Yi (2015) do not focus on structural change or skill premium growth, and do not model Korea's

⁸Examples include Lee and Yi (2018), who assess distributional outcomes in the presence of multi-stage production and worker-level comparative advantage, and Sposi et al. (2021), who incorporate dynamics and capital accumulation into a two-stage version of Antras and de Gortari (2020).

⁹Zhou (2023) can also be thought of as a multi-stage extension of Caliendo and Parro (2015), who build on Eaton and Kortum (2002) to incorporate sectoral linkages, tariffs, and trade in intermediate goods into a Ricardian model of trade.

service sector or sectoral linkages.¹⁰

The next section introduces my model. Section 3 illustrates the mechanisms driving structural change and skill premium growth following changes in trade costs, Section 4 describes how I map my model to the data and assign parameter values, Section 5 presents my counterfactual analyses, and Section 6 concludes.

2 Model

2.1 Economic Environment

Consider a world economy featuring I countries indexed by i , and S sectors indexed by s . Denote the country set \mathcal{I} and let the set of sectors be denoted \mathcal{S} . Each country is populated by a representative household, and is exogenously endowed with \bar{u}_i efficiency units of unskilled labor and \bar{h}_i efficiency units of skilled labor. Labor is inelastically supplied, and immigration is not allowed. All markets are perfectly competitive, and within each sector, a unit continuum of tradable varieties are produced in two sequential stages using constant returns technology.

First-stage varieties are produced using value added and intermediate inputs. Value added includes two types of labor, skilled and unskilled. Intermediate input usage in the production of first-stage varieties is modeled through a roundabout production structure, with a composite intermediate input aggregating final sectoral output across all sectors. This composite intermediate input captures input-output linkages between sectors. Production of second-stage varieties uses the same factors described above, in addition to an additional intermediate input, the first-stage output within the same sector. This within-sector input is referred to as the “snake” input in the literature. First- and second-stage varieties are traded among countries and trade is driven by Ricardian motives, as relative efficiencies in producing varieties differ across countries and sectors. Trade is subject to two types of trade costs, icebergs and ad-valorem tariffs. The unit measure of

¹⁰The authors note in their study that “Korea underwent an enormous structural transformation, which would necessitate modeling individual sectors and their interactions, if the calibration were to the entire economy. This is beyond the scope of this paper”. This is precisely the aim of my paper, applied to the context of India from 1995-2005.

second-stage varieties $\omega^s \in [0, 1]$ within a given sector is aggregated into a non-traded final sectoral output using constant returns technology that is identical across countries. This final sectoral output is either consumed domestically or used by domestic producers through the composite intermediate input.

2.2 Preferences

The representative household in country i derives utility from final sectoral output, with the following CES preferences:

$$U_i = \left[\sum_{s=1}^S \phi_i^s \frac{1}{\rho} [C_i^s]^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}} \quad (1)$$

where C_i^s denotes final composite output from sector s , the utility weight assigned to sector s consumption in country i is given by ϕ_i^s and the elasticity of substitution between sectors is ρ . Utility is maximized subject to the following budget constraint:

$$\sum_{s=1}^S P_i^s C_i^s = \sum_{n=1}^2 \sum_{s=1}^S (w_i^H h_i^{n,s} + w_i^L u_i^{n,s}) + TR_i \quad (2)$$

Here, TR_i denotes country i tariff revenue, and w_i^H and w_i^L denote the wages of skilled and unskilled labor, respectively. Notice that labor within each country is stage- and sector-specific, as n represents the stage of production in which labor is employed.

2.3 Sequential Production Structure

My framework used for the production of varieties is similar to the multi-sector extension of Antras and de Gortari (2020) introduced by Zhou (2023), with the addition of multiple labor types. Within each sector $s \in S$, a unit continuum of tradable varieties $\omega^s \in [0, 1]$ are produced by all countries in two sequential stages. Production of stage-one, sector s variety ω^s is produced in country i by combining value added and intermediate inputs using the following Cobb-Douglas production function:

$$y_i^{1s}(\omega^s) = \frac{1}{a_i^s(\omega^s)} (L_i^{1s}(\omega^s))^{\gamma_{is}} (I_i^{1s}(\omega^s))^{1-\gamma_{is}} \quad (3)$$

where $a_i^s(\omega^s)$ denotes the unit factor requirement for production of variety ω^s in country i , and $\gamma_{is} \in [0, 1]$ denotes the share of value added in gross output. Further, $L_i^{1s}(\omega^s)$ is a CES aggregator of skilled and unskilled labor, and $I_i^{1s}(\omega^s)$ is the composite intermediate input, which is a CES aggregator of final sectoral composite output.

Stage-two production of the same variety ω^s occurs using a similar Cobb-Douglas production function, with the added inclusion of the snake intermediate input:

$$y_i^{2s}(\omega^s) = \left[\frac{1}{a_i^s(\omega^s)} (L_i^{2s}(\omega^s))^{\gamma_{is}} (I_i^{2s}(\omega^s))^{1-\gamma_{is}} \right]^{\alpha_s} [x_i^{1s}(\omega^s)]^{1-\alpha_s} \quad (4)$$

where the stage-two input quantity $x_i^{1s}(\omega^s)$ must equal output from the previous stage, adjusted for iceberg trade costs. The parameter $\alpha_s \in [0, 1]$, which varies across sectors, determines the importance of the stage-one snake input in production of stage-two varieties. A lower value of α_s implies greater importance of the stage-one input and snake structure of production. A higher value of α_s implies less reliance on upstream input in the production of stage-two output. In the case in which $\alpha_s = 1$, the model collapses into one featuring only a single stage of production.

The labor and intermediate input bundles used in production of varieties across both stages are defined as follows:

$$L_i^{ns}(\omega^s) = \left[(\beta_i^s)^{\frac{1}{\sigma}} (u_i^{ns}(\omega^s))^{\frac{\sigma-1}{\sigma}} (1 - \beta_i^s)^{\frac{1}{\sigma}} (h_i^{ns}(\omega^s))^{\frac{\sigma-1}{\sigma}} \right] \quad (5)$$

$$I_i^{ns}(\omega^s) = \left[\sum_{j=1}^S (\psi_i^{js})^{\frac{1}{\rho_{m,s}}} [Q_i^{njs}(\omega^s)]^{\frac{\rho_{m,s}-1}{\rho_{m,s}}} \right]^{\frac{\rho_{m,s}}{\rho_{m,s}-1}} \quad (6)$$

where $L_i^{ns}(\omega^s)$ represents the bundle of skilled and unskilled workers, and $I_i^{ns}(\omega^s)$ denotes the composite intermediate used in the n th stage of production of variety ω^s in country i . In Equation (5), the unskilled labor intensity of production of sector s in country i is given by β_i^s , which is

common across all varieties within the sector. The elasticity of substitution between labor types, $\sigma > 1$, is common across all sectors and countries.

In Equation (6), $Q_i^{njs}(\omega^s)$ represents the quantity of sector j aggregate used as an input in the n th stage of production of sector s variety ω^s . Input-output linkages are governed by $\psi_i^{j,s}$, which is the weight placed on the sector j aggregate used in production of sector s varieties. The elasticity of substitution between sectoral aggregates within the sector s intermediate input bundle is $\rho_{m,s} < 1$. Notice that with the assumption that $\rho < 1$ as well, goods and services are complements from the perspective of both consumers and producers.

As mentioned earlier in this section, stage-two varieties of a given sector are aggregated within each country by a perfectly competitive firm, resulting in the production of a non-traded sectoral composite. This sectoral composite is either consumed domestically or used in roundabout production by domestic producers across all sectors. The technology used to aggregate stage-two varieties is identical for all countries:

$$Q_i^s = \left(\int_0^1 (x_i^{2,s}(\omega^s))^{\frac{\mu-1}{\mu}} d\omega^s \right)^{\frac{\mu}{\mu-1}} \quad (7)$$

where μ is the elasticity of substitution across stage-two varieties, and it is assumed $\mu > 1$.

2.4 Prices and Trade

Recall that sector s producers of stage-two varieties in country i use stage-one varieties from the same sector as an input in production, which is referred to as the "snake" input. The sourcing decision for these perfectly competitive firms is such that they purchase each stage-one variety from the lowest-cost supplier, inclusive of trade and production costs. That is:

$$p_i^{1s}(\omega^s) = \min_h \{ a_h^s(\omega^s) c_h^s \kappa_{hi}^s \} \quad (8)$$

where κ_{hi}^s denotes the combined trade costs associated with shipping sector s varieties from country h to country i , and c_h^s represents the cost of an input bundle for sector s production in

country h . Trade costs are inclusive of an iceberg component and ad valorem tariffs, and take the following form:

$$\kappa_{hi}^s = d_{hi}^s(1 + \tau_{hi}^s) \quad (9)$$

Here, d_{hi}^s denotes the iceberg trade cost associated with shipping sector s output from country h to country i , and $\tau_{hi}^s \geq 0$ denotes the ad valorem tariff imposed by country i on sector s imports from country h . It is assumed that country h must ship $d_{hi}^s \geq 1$ units of sector s output for one unit to be delivered to country i . Further, the standard assumptions are made that $d_{ii}^s = 1$ and $d_{hi}^s \leq d_{hk}^s d_{ki}^s$ for all h, i and k .

The cost of an input bundle, c_h^s , takes the form shown in Equation (10) below. Specifically, letting $P_h^{L,s}$ and $P_h^{I,s}$ denote the unit costs associated with the labor and composite intermediate bundles in country h , sector s , we have:

$$c_h^s = (\gamma_{hs})^{-\gamma_{hs}} (1 - \gamma_{hs})^{\gamma_{hs}-1} (P_h^{L,s})^{\gamma_{hs}} (P_h^{I,s})^{1-\gamma_{hs}} \quad (10)$$

$$P_h^{L,s} = [\beta_h^s (w_h^L)^{1-\sigma} + (1 - \beta_h^s) (w_h^H)^{1-\sigma}]^{\frac{1}{1-\sigma}} \quad (11)$$

$$P_h^{I,s} = \left[\sum_{j=1}^S \psi_h^{j,s} (P_h^j)^{1-\rho_{m,s}} \right]^{\frac{1}{1-\rho_{m,s}}} \quad (12)$$

where the price index in country h of the sector j composite output is given by P_h^j .

As production occurs in two sequential stages, the price of a unit of tradable stage-two variety ω^s is inclusive of the price of the stage-one variety weighted by the upstream linkage parameter $1 - \alpha_s$, as well as the production and trade costs associated with the second stage of production. This implies that the sourcing decision of the firm that aggregating stage-two varieties into the sector s composite in country i is such that the price of stage-two variety ω^s is:

$$p_i^{2s}(\omega^s) = \min_h \{ \kappa_{hi}^s (p_h^{1s}(\omega^s))^{1-\alpha_s} (a_h^s(\omega^s) c_h^s)^{\alpha_s} \} \quad (13)$$

Note that Equation (13) implies that trade costs are applied to the gross value of the variety being transported; that is, downstream trade cost κ_{hi}^s is not weighted by the downstream linkage parameter α_s . Meanwhile, the trade cost associated with shipment of the first-stage variety is embedded within $p_h^{1s}(\omega^s)$ and is therefore weighted by $1 - \alpha_s$. This framework, which follows Antras and de Gortari (2020), implies that trade costs compound along the value chain, and that downstream trade costs impact value added more so than upstream trade costs. The fact that trade costs compound implies that the elasticity of relative wages and trade flows with respect to changes in trade costs will be greater in this two-stage setting than in a one stage setting, i.e. when $\alpha_s = 1$.

2.5 Production Paths and Technology

The path of production for each variety consists of two stages, and possibly two countries. Denote the production path of variety ω^s whose final absorption occurs in country i by $\ell_i(\omega^s) = \{\ell_i^1(\omega^s), \ell_i^2(\omega^s)\}$, where $\ell_i^n(\omega^s)$ denotes the country within the chain producing at stage n . The key insight of Antras and de Gortari (2020) is that productivity can be considered at the chain level rather than at the stage level, an assumption which provides the tractability of Eaton and Kortum (2002) in the given multi-stage, multi-country setting. Given this assumption, it is useful to express the optimal production path for a sector j variety ultimately absorbed by country i as follows:

$$\ell_i^{*j}(\omega^j) = \arg \min_{\ell \in N^2} \left(a_{\ell_i^2}^j(\omega^j) c_{\ell_i^2}^j \right)^{\alpha_j} \left(a_{\ell_i^1}^j(\omega^j) c_{\ell_i^1}^j \kappa_{\ell_i^1, \ell_i^2}^j \right)^{1-\alpha_j} \kappa_{\ell_i^2, i}^j \quad (14)$$

I follow the framework of Antras and de Gortari (2020) by introducing randomness to the overall cost of production of a given chain. Precisely, the efficiency associated with a given chain ℓ_i can be characterized as follows:

$$Pr \left(a_{\ell_i^1}^j(\omega^j)^{1-\alpha_j} a_{\ell_i^2}^j(\omega^j)^{\alpha_j} \geq a \right) = \exp \{ -a^\theta \left(T_{\ell_i^1}^j \right)^{1-\alpha_j} \left(T_{\ell_i^2}^j \right)^{\alpha_j} \} \quad (15)$$

In other words, it is assumed that $a_{\ell_i^1}^j(\omega^j)^{1-\alpha_j} a_{\ell_i^2}^j(\omega^j)^{\alpha_j}$ is Fréchet distributed, with shape parameter θ and location parameter $\left(T_{\ell_i^1}^j\right)^{1-\alpha_j} \left(T_{\ell_i^2}^j\right)^{\alpha_j}$. The shape parameter is common across sectors, while the technology parameter T_i^j varies by sector and country, but not by stage. Under the framework outlined above, a closed-form expression can be obtained for the relative prevalence of various production paths in equilibrium. First, the probability of a given path ℓ_i being the cost-minimizing production path for a sector j variety ultimately absorbed in country i can be expressed:

$$\pi_{\ell^*,i}^j = \frac{\left[\kappa_{\ell_2^*,i}^j (c_{\ell_2^*}^j)^{\alpha_j} (\kappa_{\ell_1^*,\ell_2^*}^j c_{\ell_1^*}^j)^{1-\alpha_j} \right]^{-\theta} (T_{\ell_1^*}^j)^{1-\alpha_j} (T_{\ell_2^*}^j)^{\alpha_j}}{\Theta_i^j} \quad (16)$$

where Θ_i^j is the sum of the numerator over all possible production paths.¹¹ Under the assumption of a unit continuum of varieties, $\pi_{\ell^*,i}^j$ can also be interpreted as the share of production paths ultimately serving country i for which ℓ^* is the cost-minimizing path for sector j varieties. Further, it is shown in Antras and de Gortati (2020) that the distribution of final stage-two variety prices paid by country i customers is independent of the path of production ℓ . Therefore, $\pi_{\ell^*,i}^j$ can be interpreted as the share of country i , sector j expenditure which is spent on final varieties produced under path ℓ^* .

Finally, the exact price index associated with Equation (7) can be derived as:

$$P_i^j = \eta (\Theta_i^j)^{\frac{-1}{\theta}} \quad (17)$$

where $\eta = \left[\Gamma\left(\frac{\theta+1-\mu}{\theta}\right) \right]^{\frac{1}{1-\mu}}$ and Γ is the gamma function.¹² Under the calibrated shape parameter $\theta = 4$ (see Section 4), Equation (17) and the definition of Θ_i^j imply that the price of sector j composite output is decreasing in all countries' sector j productivity levels, and increasing in all countries' sector j input bundle and trade costs.

¹¹To be precise, $\Theta_i^j = \sum_{\ell \in N^2} \left(\left[\kappa_{\ell_2,i}^j (c_{\ell_2}^j)^{\alpha_j} (\kappa_{\ell_1,\ell_2}^j c_{\ell_1}^j)^{1-\alpha_j} \right]^{-\theta} (T_{\ell_1}^j)^{1-\alpha_j} (T_{\ell_2}^j)^{\alpha_j} \right)$

¹²For the exact price index to be well-defined, it is also assumed that $\mu - 1 < \theta$.

2.6 General Equilibrium

In general equilibrium, wages $\{w_i^H, w_i^L\}_{i \in I}$ are solved for such that Equations (10), (11), (12), (16), (17), and the market clearing conditions that follow are satisfied. First, aggregate markets must clear. That is, $\forall i \in \mathcal{I}, \forall s \in \mathcal{S}$

$$Q_i^s = C_i^s + \sum_{n=1}^2 \sum_{j=1}^5 \int_0^1 Q_i^{n,s,j}(\omega^j) d\omega^j \quad (18)$$

Equation (18) tells us that non-traded sectoral aggregates must either be consumed domestically, or used by domestic producers through the composite intermediate input. Next, variety markets must clear. That is, $\forall i \in \mathcal{I}, \forall s \in \mathcal{S}, \forall n \in \{1, 2\}, \forall \omega \in [0, 1]$:

$$y_i^{ns}(\omega^s) = \sum_{j=1}^5 1_{ij}^{ns}(\omega^s) x_j^{ns}(\omega^s) d_{ij}^s \quad (19)$$

where $1_{ij}^{ns}(\omega^s)$ is an indicator variable taking on a value of one if variety ω^s , which has completed its n th stage of production in country i , is purchased by country j , and a value of zero otherwise. Notice that quantities of traded varieties are adjusted for iceberg trade costs in Equation (19).

Additionally, with two types of labor employed across n stages of production for S sectors in each country, the following labor market conditions must hold $\forall i \in \mathcal{I}$:

$$\bar{u}_i = \sum_{n=1}^2 \sum_{j=1}^5 \int_0^1 u_i^{n,j}(\omega^j) d\omega^j \quad (20)$$

$$\bar{h}_i = \sum_{n=1}^2 \sum_{j=1}^5 \int_0^1 h_i^{n,j}(\omega^j) d\omega^j \quad (21)$$

where $u_i^{n,j}(\omega^j)$ and $h_i^{n,j}(\omega^j)$ denote the quantities of unskilled and skilled labor, respectively, employed in the n th stage of production of variety ω^j in country i .

Assuming perfectly competitive markets, in general equilibrium it must also be the case that

payments to each labor type within each country and sector equal revenues generated by the labor. There is one such condition for every labor type, country, and sector combination. The model is calibrated with three countries and five sectors, yielding a total of 30 equations. For example, consider unskilled labor employed in sector s within country i . Letting Λ_n^i denote the set of production paths under which country i is the stage- n producer, the following must hold in equilibrium:

$$\begin{aligned}
w_i^L u_i^s = & \underbrace{\gamma_{is} \beta_i^s \left[\frac{P_i^{L,s}}{w_i^L} \right]^{\sigma-1}}_{(1)} \times \underbrace{\left[\frac{\alpha_s}{1 + \tau_{in}^j} \sum_{n=1}^N \sum_{\ell \in \Lambda_2^i} \pi_{\ell,n}^s \left(\right. \right.}_{(2)} \\
& (w_n^L u_n + w_n^H h_n + T R_n) \left(\frac{\phi_n^s (P_n^s)^{1-\rho}}{\sum_{s'} \phi_n^{s'} (P_n^{s'})^{1-\rho}} \right) + \sum_j \left(\frac{1 - \gamma_{nj}}{\gamma_{nj}} \psi_n^{s,j} \left(\frac{P_n^{I,j}}{P_n^s} \right)^{\rho_{m,j}-1} (w_n^L u_n^j + w_n^H h_n^j) \right) \left. \right. \\
& + \underbrace{\frac{1 - \alpha_s}{(1 + \tau_{in}^j)(1 + \tau_{nc}^j)} \sum_{n=1}^N \sum_{c=1}^N \sum_{\ell \in \Lambda_1^i \cap \Lambda_2^n} \pi_{\ell,c}^s \left(\right.}_{(3)} \\
& \left. \left. (w_c^L u_c + w_c^H h_c + T R_c) \left(\frac{\phi_c^s (P_c^s)^{1-\rho}}{\sum_{s'} \phi_c^{s'} (P_c^{s'})^{1-\rho}} \right) + \sum_j \left(\frac{1 - \gamma_{cj}}{\gamma_{cj}} \psi_c^{s,j} \left(\frac{P_c^{I,j}}{P_c^s} \right)^{\rho_{m,j}-1} (w_c^L u_c^j + w_c^H h_c^j) \right) \right) \right] \right] \quad (22)
\end{aligned}$$

First, notice that the Cobb-Douglas production structure given by Equations (3) and (4), and the formula for the CES aggregator of skilled and unskilled labor shown in Equation (5) imply that from the perspective of a sector s firm producing in country i , payments to unskilled labor as a share of total input expenditure is given by the first underbraced expression in Equation (22). These payments are split across two stages of production.

The second underbraced expression in Equation (22), together with the entire second line of the equation, represent total revenues generated by second-stage production of sector s varieties in country i . These revenues include a component representing varieties embedded in sector s composite purchases by final consumers, and a component representing varieties embedded in sector s composite input expenditure by firms (of all sectors).¹³ These purchases are summed across all

¹³For country i producers of sector j varieties, total input expenditure on the composite intermediate input is equal to $\frac{1 - \gamma_{ij}}{\gamma_{ij}}$ times total payments to labor.

countries, and weighted by the share of each country's purchases on varieties produced along paths for which country i is the second-stage producer, as is indicated by the second underbraced expression in Equation (22).¹⁴ Note that under the assumed tariff structure, country i receives $\frac{1}{1+\tau_{in}^j}$ of total expenditure by country n on country i , sector j exports.

The last two lines of Equation (22) represent total payments to factors used in the production of first-stage, sector s varieties in country i . Specifically, the last line represents final and intermediate demand for sector s composite output, while the third line represents the share of the total revenue that is paid out to stage-one factors in country i . This derivation is similar to the one described in the preceding paragraph, the main difference being that two layers of tariffs must now be accounted for: the tariff applied on each tradable variety following first-stage production, and the tariff applied following second-stage production. For this reason, the summation across purchasing countries now becomes a double summation, one across stage-two producing countries using the stage-one variety as a snake input, and one across final purchasing countries aggregating the stage-two varieties into the sectoral composite output.¹⁵ Similar expressions to Equation (22) can be derived for both labor types across all sectors and countries.

Following Zhou (2023), tariff revenue consists of three components: revenue from tariffs imposed on imports of stage-two varieties ultimately absorbed through final consumption, on stage-two varieties ultimately absorbed through roundabout production, and on stage-one varieties used as snake inputs. The derivations for each of these three components can be found in the Section A.1 of the Appendix.

To solve the model, I apply a modified version of the Alvarez and Lucas (2007) algorithm. First, an initial guess of wages $\{w_i^L, w_i^H\}_{i \in I}$ is made, from which $\{P_i^s\}_{i \in HI, s \in S}$ can be solved for. All other equilibrium variables can then be calculated using Equations (10), (11), (12), and (16), allowing me to set up the system of 30 labor market clearing equations outlined by Equation (22) and then solve for the labor allocation $\{u_i^s, h_i^s\}_{i \in I, s \in S}$ that clears factor markets. I then calculate excess labor demand implied by this allocation and the labor endowments $\{\bar{u}_i, \bar{h}_i\}_{i \in I}$. The initial

¹⁴Note here that the share of payments to second-stage factors from purchases of final sector s varieties is α_s .

¹⁵See third underbraced expression in Equation (22).

guess of the wage vector is then updated accordingly, and this process is iterated until excess labor demand approaches zero and the convergence criterion is met.

3 Mechanisms: Structural Change and Skill Premium Growth

In this section, I illustrate the mechanisms underlying structural change and skill premium growth induced by changes in trade costs. A number of simplifying assumptions will be made to clarify the core mechanisms before moving onto the fully calibrated model. First, assume that there exist only two sectors in the world economy, goods and services, and that there are two symmetric countries (i.e. $s \in \{G, S\}, i \in \{1, 2\}$). Assume that iceberg trade costs are the only trade costs present in this simplified economy ($\kappa_{hi}^s = d_{hi}^s$), and for now assume no composite intermediate usage ($\gamma_{ig} = \gamma_{is} = 1$). Let goods and services be complements in consumption ($\rho \in (0, 1)$), with utility weights being equal for both sectors ($\phi_i^S = \phi_i^G$). Finally, assume that goods production is completely unskilled labor-intensive ($\beta_i^g = 1$), and that service production is completely skilled labor-intensive ($\beta_i^s = 0$). While it is instructive to cover the closed economy case prior to illustrating structural change in an open economy, I only cover the open economy case in this section, as this paper specifically asks what the effects of *trade costs* are on structural change and skill premium growth, and abstracts away from other potential mechanisms such as sector-biased productivity growth. I include the closed economy case in Section A.3 of the Appendix.

3.1 Open Economy Setting

Suppose that iceberg trade costs are sufficiently low such that trade occurs between the two countries in our simplified world economy. Note that balanced trade is assumed by the representative consumer's budget constraint. With international trade in general, expenditure shares need not equal production shares as is the case in a closed economy. This is because countries can specialize according to their comparative advantage and become a net exporter of a one sector's output while becoming a net importer of the other sector's output. Thus, as is discussed by Lee (2023), the

value added share for sector j in country i in this setting can be thought of as the sum of country i 's expenditure share on sector j and a term capturing sectoral net exports due to specialization.

While the case of asymmetric trade costs will be discussed later in this section, we begin by assuming symmetric countries, and therefore symmetric trade costs. This assumption leads to sectoral consumption shares equalling production shares (and thus value added shares) in this simple open economy setting. The following relationship must therefore hold:

$$\underbrace{\left(\frac{P_i^S}{P_i^G}\right)^{1-\rho}}_{(1)} = \frac{P_i^S C_i^S}{P_i^G C_i^G} = \underbrace{\frac{P_i^S Q_i^S}{P_i^G Q_i^G}}_{(2)} = \frac{\nu_i^S}{\nu_i^G} \quad (23)$$

where ν_i^j denotes the share of sector j in country i value added. The first underbraced expression follows from household utility optimization, and the second underbraced expression holds due to the fact that labor is the only factor of production employed in production across both sectors. Given the assumption that $\rho \in (0, 1)$, Equation (23) demonstrates that if the price of goods relative to services decreases in country i , the relative value added share for services must increase. This mechanism is what the structural change literature refers to as the "price effect". In this setting, structural change and skill premium growth can be driven by changes in trade costs or sector-biased productivity growth. To see this, substitute Equation (17) into the left-hand side of Equation (23), and after rearranging we have:¹⁶

$$\left(\frac{u_i}{h_i}\right)^{\frac{1-\rho}{\rho}} \left[\left(\frac{T_i^G}{T_i^S}\right) \frac{\pi_{(i,i),i}^S}{\pi_{(i,i),i}^G} \right]^{\frac{1-\rho}{\rho\theta}} = \frac{\nu_i^S}{\nu_i^G} \quad (24)$$

Then, dividing both sides of Equation (25) by $\frac{h_i}{u_i}$:

$$\left(\frac{u_i}{h_i}\right)^{\frac{1}{\rho}} \left[\left(\frac{T_i^G}{T_i^S}\right) \frac{\pi_{(i,i),i}^S}{\pi_{(i,i),i}^G} \right]^{\frac{1-\rho}{\rho\theta}} = \frac{w_i^H}{w_i^L} \quad (25)$$

where $\pi_{(i,i),i}^j$ denotes the share of sector j expenditure in country i on final varieties produced along a purely domestic production path. Observing these relationships, we can see that if trade

¹⁶In deriving Equation (25), note that our simplifying assumptions imply $\nu_i^S = w^H h_i$ and $\nu_i^G = w^L u_i$.

costs change in a way such that goods import cost reductions country i exceed service import cost reductions (implying that $\frac{\pi_{(i,i),i}^S}{\pi_{(i,i),i}^G}$ increases), service sector and skill premium growth occur in country i . In the two-stage setting, still assuming symmetric countries and thus symmetric trade costs ($\kappa_{12}^j = \kappa_{21}^j = \kappa^j \forall j \in \{G, S\}$), it can be shown that the elasticity of the skill premium with respect to absolute changes in goods sector trade costs is:¹⁷

$$\frac{\partial \ln \left(\frac{w_i^H}{w_i^L} \right)}{\partial \kappa^G} = \frac{-(1-\rho)}{\rho \kappa^G} \left(\underbrace{\frac{1}{1 + (\kappa^G)^\theta}}_{(1)} + \underbrace{\frac{1 - \alpha_G}{1 + (\kappa^G)^{\theta(1-\alpha_G)}}}_{(2)} \right) \quad (26)$$

Assuming $\rho \in (0, 1)$, $\alpha_G \in [0, 1]$, and $\theta > 0$, Equation (29) implies that all else equal, reductions in goods sector trade costs increase the skill premium. In Equation (26), the first underbraced expression represents the impact of changes in goods sector trade costs on the skill premium attributable to trade in second-stage output, and the second underbraced expression represents the portion attributable to trade in first stage output. Recalling that the model collapses into a one-stage model when $\alpha_G = \alpha_S = 1$, this Equation shows that the elasticity of relative wages with respect to changes in trade costs is larger in a model with two stages than in a model with one stage, such as that used by Sotelo and Cravino (2018).¹⁸ Additionally, Equations (24)-(26) illustrate that sectoral value added shares and the skill premium can move in the same direction for *all* countries in this model through the price effect, if trade costs move symmetrically as is the case in this example.

While the example above demonstrates how symmetric changes in trade costs can drive structural change and skill premium growth, we can take this example one step further by illustrating these mechanisms in the presence of asymmetric trade costs. A key assumption during my calibration of the full model is that I allow for asymmetry in trade costs; that is, import costs do not need to equal export costs for each country ($\kappa_{12}^j \neq \kappa_{21}^j \forall j \in \{G, S\}$). With this in mind, using Equation (16) we can rewrite Equation (24) from the perspective of countries 1 and 2:

¹⁷See Appendix for full derivation.

¹⁸Key assumption here is that trade costs are proportional to gross value of good being shipped, as in Antras and de Gortari (2020).

$$\left(\frac{u_1}{h_1}\right)^{\frac{1-\rho}{\rho}} \left(\frac{T_1^G}{T_1^S}\right)^{\frac{1-\rho}{\rho\theta}} \left[\frac{1 + (\kappa_{12}^S)^{1-\alpha_S} \kappa_{21}^S + \kappa_{21}^S + (\kappa_{21}^S)^{1-\alpha_S}}{1 + (\kappa_{12}^G)^{1-\alpha_G} \kappa_{21}^G + \kappa_{21}^G + (\kappa_{21}^G)^{1-\alpha_G}} \right]^{\frac{1-\rho}{\rho}} = \frac{\nu_1^S}{\nu_1^G} \quad (27)$$

$$\left(\frac{u_2}{h_2}\right)^{\frac{1-\rho}{\rho}} \left(\frac{T_2^G}{T_2^S}\right)^{\frac{1-\rho}{\rho\theta}} \left[\frac{1 + (\kappa_{21}^S)^{1-\alpha_S} \kappa_{12}^S + \kappa_{12}^S + (\kappa_{12}^S)^{1-\alpha_S}}{1 + (\kappa_{21}^G)^{1-\alpha_G} \kappa_{12}^G + \kappa_{12}^G + (\kappa_{12}^G)^{1-\alpha_G}} \right]^{\frac{1-\rho}{\rho}} = \frac{\nu_2^S}{\nu_2^G} \quad (28)$$

From Equation (27), we can see how import costs affect relative value added shares in country 1. Specifically, Equation (27) implies that a decrease in goods sector import costs (κ_{21}^G) relative to service sector import costs (κ_{21}^S) increases the value added share of services in country 1. Intuitively, there are two channels at play here. First, the price effect implies that country 1's expenditure share on services increases as the relative price of goods declines.¹⁹ If the change in trade costs is not symmetric, meaning that κ_{21}^G declines but κ_{12}^G does not, then from Equations (27) and (28) we can gather that the price effect will be much larger in country 1 than in country 2. Recalling that consumption shares do not need to equal production shares in an open economy, country 1 will increase its trade deficit in the goods sector, increasing its imports of goods as the cost of importing goods relative to services declines. Balanced trade implies that country 1 must increase its trade surplus in the service sector, boosting service exports, while country 2 increases its trade surplus in the goods sector. Together, these changes in sectoral net exports result in country 1 increasing its value added share in services, and country 2 increasing its value added share in goods.

Export costs for country 1 play a larger role in Equation (28), which illustrates that reductions in service export costs (κ_{12}^S) relative to goods export costs (κ_{12}^G) for country 1 drive a contraction of the service sector in country 2. Through the process described in the previous paragraph, balanced trade implies that country 1 will increase its value added share in services, while country 2 increases its value added share in goods. Therefore, in the presence of asymmetric changes in trade costs, both the price effect and sectoral net export (i.e. specialization) effects discussed at the beginning of this section are operative. Thus, if trade costs change so that country 1 experiences

¹⁹From Equation (17) and the definition of Θ_i^j , we know that the exact price index of goods in country 1 is decreasing in goods sector import costs.

reductions in goods import costs and service export costs, as was the case in India from 1995-2005, then its service sector as a share of total value added will increase. As the service sector uses skilled labor intensively in production, the expansion of the service sector will lead to a relative increase in the return to skilled labor.

Finally, note that if we allow for intermediate input usage in production ($\gamma_{i,G}, \gamma_{i,S} < 1$), then the mechanisms outlined above will be reinforced, given Equation (12) and our assumption that goods and services are complements in production ($\rho_{m,G}, \rho_{m,S} < 1$). In this case, expenditure shares move in the same direction for consumers and producers in response to changes in the relative price of goods and services. The magnitude of this effect will depend on sectoral consumption and production weights, (ϕ_i^j and $\psi_i^{j,s}$), and the elasticity of substitution between sectors in consumption and production (ρ_j and $\rho_{m,j}$), with a larger shift in expenditure shares occurring the closer $\rho_{m,j}$ and ρ_j are to zero.

4 Data and Calibration

In this section, I describe how I map my full model to the data and assign parameter values prior to running my counterfactual analyses. I calibrate my model to three countries - India, the United States, and a constructed "rest of the world" (ROW) - in the year 1995. I use the World Input-Output Database (WIOD) and aggregate industries into five sectors: agriculture and mining, manufactured consumer goods, manufactured producer goods, skilled services, and unskilled services. Data on labor endowments and sectoral skill intensities comes from the WIOD Socio Economic Accounts. Tariff data is sourced from the World Bank World Integrated Trade Solution (WITS) database. When assigning parameter values, some values are directly assigned from outside of the model, others are calculated using data, and others are set to match moments characterizing the world economy in 1995.

4.1 Rationale for Five Sectors

In my baseline calibration, I aggregate industries into five sectors: agriculture and mining, manufactured consumer goods, manufactured producer goods, skilled services, and unskilled services. This sector choice allows me to capture differences in skill intensities across goods-producing industries and across service industries that are quantitatively important when considering the reallocation of value added following trade cost changes. Further, this sector choice allows me to assess the differential impact of consumer goods tariffs and producer goods tariffs, thus contributing to the tariff escalation literature. The exact concordance between industries and sectors used can be found in Section A.5.

Skilled and unskilled services are differentiated due to the fact that skilled services are, on average, much more skilled labor intensive than unskilled services (see Figure 2). Similarly, consumer goods and producer goods are differentiated due to the discrepancy between skilled labor intensities between the two sectors. Regarding the methodology used to divide the manufacturing sector into consumer and producer goods, I partition industries according to each's end use in India, as observed in the WIOD table for 1995. Specifically, I observe all Indian absorption of manufactured goods in 1995, and split the absorption into two categories: absorption that takes the form of intermediate usage or investment, and absorption that takes the form of final consumption expenditure. The results from my aggregation of manufacturing industries can be seen in Table 1. The results show that of India's total consumption expenditure on manufactured goods in 1995, 73% was on goods that I classify as consumer goods. Similarly, of India's absorption of manufactured goods taking the form of intermediate usage or investment, 67% was on goods that I classify as producer goods. In the context of my model, the consumer goods sector has a higher utility weight assigned in the consumer's utility function, and the producer goods sector has higher intermediate input weights assigned in the producer's composite intermediate good.

The distinction between consumer goods and producer goods is quantitatively important in my counterfactual exercises because the production of producer goods is, on average, more skilled labor intensive than production of consumer goods in India. Further, production of producer goods

Table 1: Categorization of Manufacturing Industries Into Consumer and Producer Goods Sectors

Industry Categorization	Share of Indian Absorption of Manufacturing Output by End Use (1995)	
	Intermediate Usage or Investment	Consumption Expenditure
Consumer Goods	33%	73%
Producer Goods	67%	27%
Total	100%	100%

Source(s): WIOD

is more skilled labor intensive than unskilled service production in India throughout the entire time period analyzed. This can be seen in Figure 5 in the Appendix, which presents the same picture as Figure 2, now splitting manufacturing into two sub-sectors. This nuance captures the fact that even though manufacturing is less skilled labor intensive than service production in the aggregate, this is not necessarily the case when comparing all manufacturing industries with all service industries. An alternative calibration in which manufacturing industries are aggregated into only one sector and all service industries are aggregated into only one sector would miss this nuance entirely.

A key mechanism in my model involves the sectoral reallocation of value added and the associated implications for the skill premium following import cost reductions (and tariff reductions in particular) in the goods sector. Given the skill intensity discrepancy outlined above, import cost reductions in the producer goods sector may have vastly different implications for the skill premium than import cost reductions in the consumer goods sector. For example, if producer goods tariffs are reduced in India, the price effect implies that value added will be reallocated across the other sectors. Production of both consumer goods and unskilled services is less skilled labor intensive than the production of producer goods, implying that it is possible that enough value added is reallocated to these sectors that the skill premium actually decreases following tariff reductions in the producer goods sector. As will be seen in my counterfactual exercises that follow, this is indeed the case. Meanwhile, as the production of consumer goods is very unskilled labor intensive, tariff reductions for consumer goods will drive an increase in the skill premium, as value added is mostly reallocated to more skilled labor intensive sectors, hence increasing the return to skilled la-

bor. Thus, the relative magnitude of consumer goods import cost reductions compared to producer goods import cost reductions influences the direction in which the skill premium moves.

4.2 Predetermined Parameters

In my benchmark calibration, the elasticity of substitution between sectors in utility, ρ , and elasticity of substitution between sectors in production, ρ_m^s , are taken from the literature. I assign $\rho = 0.26$ following Comin et al. (2015), and $\rho_m^s = \rho_m = .0001$ following Sotelo and Cravino (2018).²⁰ The elasticity of substitution between labor types, $\sigma = 1.48$, is taken from Sotelo and Cravino (2018) as well. The stage-invariant component of the trade elasticity, $\theta = 4$, is taken from Simonovska and Waugh (2014), while the assigned value of the elasticity of substitution between stage-two varieties is $\mu = 2$. All of these parameter values can be found in Table 7, in the Appendix. Finally, tariff data is sourced from the World Bank World Integrated Trade Solution (WITS) database, using the methodology outlined by Mayer et al. (2023) in the construction of the CEPII Trade and Production Database.²¹

4.3 Expenditure Shares

The expenditure shares given in Equation (16), $\pi_{\ell,i}^i$, are not directly observable in the input-output data that I use in my analysis, as the data does not track cross-sector linkages across each individual stage along the path of production of goods and services. However, a mapping does exist from $\pi_{\ell,i}^i$ to the expenditure shares that are observable in the WIOD, and these observable shares are what I use when calibrating productivity parameters and trade costs. Specifically, let $\Pi_{ji}^{F,s}$ denote final sector s expenditure made by country i on output whose last stage of production took place in country j , as a share of total final sector s expenditure made by country i . Similarly, let $\Pi_{ji}^{I,s}$ denote intermediate sector s expenditure made by country i on country j output, as a share of total intermediate sector s expenditure made by country i . These two expenditure shares can be read off

²⁰Note that with the assigned value for ρ_m^s , sectors are assumed to be near perfect complements in production. This assumption is consistent with the assumptions made in the construction of the input-output tables used in the literature.

²¹See Section A.7 for details regarding the calculation of tariffs.

from the WIOD tables for every country pair, across all sectors. The mapping from these shares to my model can be expressed as follows:

$$\Pi_{ji}^{F,s} = \frac{X_{ji}^{consumption,s}}{\sum_{n=1}^N X_{ni}^{consumption,s}} \quad (29)$$

$$\Pi_{ji}^{I,s} = \frac{X_{ji}^{round,s} + X_{ii}^{snake,s}}{\sum_{n=1}^N (X_{ni}^{round,s} + X_{ni}^{snake,s})} \quad (30)$$

where $X_{ji}^{consumption,s}$ denotes country i final consumption expenditure on sector s output sourced from country j , $X_{ji}^{round,s}$ is country i expenditure on sector s output used in roundabout production, and $X_{ji}^{snake,s}$ is country i expenditure on sector s snake inputs sourced from country j . The derivations for each of these expenditure flows can be found in Section A.2. Finally, total sector s expenditure made by country i on country j gross output, as a share of total sector s expenditure by country i can be expressed:

$$\Pi_{ji}^s = \frac{X_{ji}^{consumption,s} + X_{ji}^{round,s} + X_{ii}^{snake,s}}{\sum_{n=1}^N (X_{ni}^{consumption,s} + X_{ni}^{round,s} + X_{ni}^{snake,s})} \quad (31)$$

4.4 Calibrated Parameters

The sectoral utility weights, ϕ_i^s , are calibrated to match country-level final expenditure shares in the baseline year, with these shares calculated using the WIOD 1995 data. Production parameter γ_i^s is calibrated to match sectoral ratios of value added to gross output, $\psi_i^{j,s}$ is calibrated to match sectoral input expenditure shares, and β_i^s to match sectoral relative payments to skilled and unskilled workers in 1995. Productivity parameters, T_i^s , are calibrated to match country-level sectoral value added shares as well as domestic expenditure shares, Π_{ii}^s , in the baseline year.

Regarding the parameter determining the relative weighting assigned to upstream and downstream production, α^s , I calibrate this parameter jointly targeting country-level gross output shares and domestic expenditure shares in the baseline year. As is discussed further in Section 5, the inclusion of two stages of production in my model allows for the flexibility to match these shares,

which is not possible in a one-stage model given my calibration strategy. Specifically, in a model featuring only one stage of production, the size of India’s economy as a share of world gross output would be significantly overestimated. Table 2, shown below, lists each of the calibrated parameters discussed in this section along with the moments targeted in calibration of these parameters.

Table 2: Internal Calibration

Parameter(s)	Description	Target(s)
β_i^s	Unskilled labor weights	Relative payments to skilled and unskilled workers in 1995
$\psi_i^{s,s'}$	Sectoral input weights	Input expenditure shares in 1995
ϕ_s	Sectoral utility weights	Final expenditure shares in 1995
γ_i^s	Value added shares	Sectoral VA/GO in 1995
T_i^s	Productivity parameters	Sectoral VA shares, domestic expenditure shares in 1995
α^s	Stage-2 production intensity	Domestic expenditure shares; Country-level gross output shares

4.5 Calibration of Trade Costs

Trade costs can be backed out from gross output price data and entries from the WIOD tables using the following relationship implied by my structural model, which can be derived using Equations (16) and (17):

$$\kappa_{ij}^s = \left(\frac{\pi_{(i,i),j}^s}{\pi_{(i,i),i}^s} \right)^{\frac{-1}{\theta}} \frac{P_j^s}{P_i^s} \quad (32)$$

Using a methodology similar to Lee (2023), I measure sectoral prices P_j^s using gross output price data. Specifically, cross-country gross output price levels are sourced from the Productivity Level Database 2005 Benchmark database (Inklaar and Timmer (2014)), and within-country variation in sectoral price levels over time is sourced from the WIOD Socio Economic Accounts. These two datasets combined provide cross-country price levels for 35 industries, across the entire time frame of my analysis. I aggregate these industry-level prices in each year to the sector-level, using annual industry shares of gross output as weights. The rest of the world prices are imputed using price data for the 23 countries in my rest of the world grouping discussed at the beginning of this

section for which a full sequence of sectoral prices is available. See Section A.8 for a complete description of this imputation procedure.

Regarding the expenditure shares in Equation (32), recall from the discussion in Section 4.3 that these shares are not directly observable in the WIOD tables. However, it can be shown using Equation (16) that the ratio $\frac{\pi_{(i,i),j}^s}{\pi_{(i,i),i}^s}$ is equivalent to $\frac{\Pi_{i,j}^{F,s}}{\Pi_{i,i}^{F,s}}$ (see Section A.9 for proof), which is directly observable in the data. Therefore, we can rewrite Equation (32) as follows:

$$\kappa_{ij}^s = \left(\frac{\Pi_{i,j}^{F,s}}{\Pi_{i,i}^{F,s}} \right)^{\frac{-1}{\theta}} \frac{P_j^s}{P_i^s} \quad (33)$$

and the calibration of trade costs in my two-stage model is therefore equivalent to the calibration of trade costs in a one-stage model such as Lee (2023). This paper is the first to my knowledge to calibrate trade costs asymmetrically using the multi-stage framework of Antras and de Gortari (2020). As noted by Waugh (2010), poor countries face higher costs to export relative to rich countries, and thus the assumption of symmetric trade costs would be incorrect in an environment such as my own, in which India trades with the U.S. Accounting for these asymmetries is important in my analysis, as the main mechanism inducing structural change and skill premium growth entails trade costs changing in such a way that export costs and import costs move asymmetrically for India.

Calibrated trade costs for India can be found in Figures 6 and 7 in the Appendix. As expected, export costs are higher than import costs across all sectors and years for India. The sectors in which India experiences the largest change in the cost of exporting relative to importing are skilled and unskilled services, for which India experiences a significant decline in the relative cost of exporting from 1995-2005. As will be seen in Section 5, this trend drives a large share of service sector and skill premium growth in India, as the reduction in export costs relative to import costs strengthened India's comparative advantage in service production. Interestingly, calibrated goods import costs do not decrease as one might expect given the tariff reductions that occurred over this time frame. Import costs and export costs move similarly for consumer goods and agriculture, whereas the relative cost of exporting producer goods actually falls slightly for India over the time

frame. Recalling that κ_{ij}^s includes both iceberg trade costs and tariffs, and that tariffs are directly observable, the trends seen in Figures 6 and 7 imply that iceberg import costs increased for India in the goods sector during this time period (perhaps due to non-tariff trade barriers or internal frictions that are not directly modeled in this paper), whereas tariffs fell.

5 Counterfactuals

With the model parameters calibrated to the world economy in the baseline year of 1995, I run four counterfactual exercises to quantify how much of India's structural change and rising skill premium can be explained by changes in trade costs. The counterfactual exercises are as follows:

- **Counterfactual 1** - Solve model allowing all trade costs (icebergs and tariffs) to change from 1995 to 2005 levels, leaving all other parameters unchanged from 1995 baseline.
- **Counterfactual 2** - Isolate the impact of tariff and iceberg trade cost changes separately in the counterfactual exercise described above.
- **Counterfactual 3** - Isolate the impact of changing consumer goods and producer goods tariffs, leaving icebergs and all other parameters unchanged.
- **Counterfactual 4** - Recalibrate baseline with only one stage of production, then run the same exercises as above.

The goal of the first counterfactual exercise is to quantify how much of India's structural change and rising skill premium can be explained by all changes in trade costs in my two-stage model. The second and third counterfactual exercises decompose the overall impact found in the first counterfactual exercise into the contributions made by separate components of trade costs. The last counterfactual shows that the inclusion of two stages of production in my model is quantitatively important in explaining structural change and skill premium growth.

The results of the first two counterfactual exercises can be seen in Table 3. Combined, the impact of changing icebergs and tariffs can explain 46% of India's service sector growth, 56% of

Table 3: Impact of Trade Cost Changes on India (Counterfactuals 1 and 2)

Variable	Data	Counterfactual Change in Trade Costs		
		Δ All Trade Costs	Δ Icebergs	Δ Tariffs
Δ Service VA Share (% GDP)	8.7	4.0	2.3	0.9
Δ Manufacturing VA Share (% GDP)	-2.5	-1.4	-0.1	-1.2
Δ Agriculture VA Share (% GDP)	-6.3	-2.6	-2.2	0.3
% Δ Skill Premium	9.2	6.8	3.7	0.7

its manufacturing decline, 41% of its agricultural decline, and 74% of its skill premium growth during the period 1995-2005. Changes in iceberg trade costs in particular, which mainly capture India's service export cost reductions, can explain much of India's service sector growth and skill premium growth, but explain essentially none of India's manufacturing decline.

The last column in Table 3 highlights the importance of isolating the impact of tariff reductions from changes in calibrated trade costs as a whole. Recall from Section 4.5 that the calibrated goods import costs do not change substantially over time for India. Therefore, a model that only considers changes in aggregate trade costs as estimated by Equation (33) without distinguishing between tariff and non-tariff components would miss the contribution of trade policy on India's manufacturing decline. In my counterfactual analysis I am able to differentiate between the contribution to structural change and skill premium growth made by tariff reductions, which are measurable, and the contribution made by inferred iceberg trade costs. My counterfactual analysis finds that tariff reductions alone can explain almost half of India's observed manufacturing decline. It is worth noting as well that interaction effects between changing icebergs and tariffs are present, and this interaction appears to be important in explaining India's service sector and skill premium growth. The results of counterfactuals 1 and 2 together imply that of the 8.7 percentage point increase in India's service value added share, 1.7 percentage points can be attributed to tariff reductions and the interaction between tariff reductions and changing icebergs. Similarly, of India's observed 9.2% skill premium growth, 3.1% can be attributed to tariff reductions and interaction effects.

The results of the third counterfactual exercise, in which the differential impact of consumer and producer goods tariff reductions is quantified, are reported out in Table 4. Of note is the fact

Table 4: Impact of Changing Tariffs (Counterfactual 3)

Variable	Data	Counterfactual Change in Tariffs		
		Δ All	Δ Consumer Goods	Δ Producer Goods
Δ Service VA Share (% GDP)	8.7	0.9	0.3	0.3
Δ Manufacturing VA Share (% GDP)	-2.5	-1.2	-0.5	-1.1
Δ Agriculture VA Share (% GDP)	-6.3	0.3	0.2	0.8
% Δ Skill Premium	9.2	0.7	0.4	-0.2

that both reductions in consumer and producer goods tariffs can separately explain much of India's manufacturing decline (with producer goods tariffs having a larger impact), while the interaction between the two is smaller than the sum of the separate effects. The key finding of this exercise is that consumer and producer goods tariff reductions have opposing effects on the skill premium in India, with reductions in consumer goods tariffs increasing the skill premium and reductions in producer goods tariffs reducing the skill premium. This finding confirms the hypothesis outlined in Section 4.1. Specifically, through the relative price effect and different skill intensities of producer and consumer goods, tariff reductions in producer goods will reallocate domestic value added toward less skilled intensive sectors and therefore decrease the skill premium, whereas tariff reductions in consumer goods will reallocate value added toward more skilled intensive sectors and increase the skill premium.

This finding is of particular importance due its policy implications for the Indian government and connection with the tariff escalation literature, which attempts to rationalize the fact that tariffs on inputs tend to be lower than tariffs on final goods. In the context of India, Topalova and Khandelwal (2011) establish a causal link between tariffs and firm productivity, finding both final goods and input tariffs to increase firm-level productivity, with input tariffs having a larger impact. Similarly, Goldberg et al. (2010) estimates gains from trade through access to new imported inputs following Indian trade liberalization, finding that lower input tariffs increase domestic firm product scope. Recalling that consumer goods as defined in this paper are most often final goods, and producer goods are most often intermediates, my quantitative analysis adds to this literature. Namely,

Table 5: Comparison of Two-Stage and One-Stage Models (Counterfactual 4)

Variable	Data	Counterfactual Change in All Trade Costs	
		Two-Stage Model	One-Stage Model
Δ Service VA Share (% GDP)	8.7	4.0	-0.3
Δ Manufacturing VA Share (% GDP)	-2.5	-1.4	1.0
Δ Agriculture VA Share (% GDP)	-6.3	-2.6	-0.7
% Δ Skill Premium	9.2	6.8	0.4

my findings support a new rationale for tariff escalation in India, in that that the skill premium does not widen following producer goods tariff reductions, whereas it does following consumer goods tariff reductions.

Finally, in my fourth counterfactual exercise, I set $\alpha_s = 1$ in all sectors, collapsing my model into one featuring a single stage of production. In such a model, the roundabout intermediate is the only intermediate input used in production, as no stage-one varieties are produced. I then recalibrate the model, matching the moments outlined in Table 2, then run the initial counterfactual exercise with this newly recalibrated model. The results of this counterfactual exercise are reported out in Table 5, which compares the initial results generated by my two-stage model with those obtained with the one-stage model. It is apparent upon observing these results that a model featuring two stages of sequential production does a vastly better job in explaining India's observed structural change and skill premium growth than a model with only one stage of production. In fact, India's service and manufacturing sector value added shares move in the opposite direction as what is observed in the data when trade cost changes are simulated using the one-stage model. Additionally, the one-stage model only generates 0.4% skill premium growth following changes in trade costs, compared to 6.8% generated by the two-stage model.

The key mechanism at play here relates to the amplified elasticity of relative wages to changes in trade costs shown in Equation (26) that is present in a two-stage model. This elasticity allows the two-stage model to more accurately characterize the response of wages and value added shares to changing import and export costs than a one-stage model. Additionally, the additional parameters available in the two-stage model allow the baseline calibration to come much closer to matching

Table 6: Country-Level Shares of World Gross Output (Counterfactual 4)

Country	% World Gross Output (Data)	% World Gross Output (Baseline Calibration)	
		Two-Stage Model	One-Stage Model
India	1.3	2.2	56.3
United States	24.5	21.4	6.9
Rest of World	74.2	76.4	36.8
Total	100	100	100

additional moments observed in the data that cannot be matched in a one-stage model, given my calibration strategy. Specifically, when comparing country-level shares of world gross output in the baseline calibration of my one- and two-stage models, the two-stage model comes close to matching these shares, whereas India's gross output share is greatly overestimated in the one-stage model (see Table 6). The reason underlying this discrepancy is that given my calibrated trade costs and externally assigned parameter values, a one-stage model cannot rationalize the fact that India traded so little in the baseline year without assigning unrealistically large sectoral productivity levels to India. A higher sensitivity of trade flows to trade costs than what is present in the one-stage model is needed to rationalize India's high domestic expenditure shares, and this is exactly what is generated by the two-stage model.

To summarize the main results found in my counterfactual exercises, I find that i) through the lens of my two-stage model, changes in trade costs can explain a substantial portion of India's structural change and skill premium growth from 1995-2005, ii) consumer goods and producer goods tariff reductions have opposing effects on the skill premium, and iii) a one-stage model fails to explain much, if any, of India's observed structural change and skill premium growth.

6 Conclusion

India's economic experience in the 1990s and early 2000s was largely marked by structural change driven by rapid service sector growth and declining manufacturing and agriculture value added shares. This reallocation of value added across sectors occurred concurrently alongside an in-

crease in the relative return to college-educated labor, i.e. skill premium growth. This paper finds that changes in trade costs can explain 46% of India's service sector growth, 56% of India's manufacturing sector decline, 41% of its agricultural decline, and 74% of its skill premium growth from 1995-2005. Both tariff reductions and changes in other trade costs, captured by iceberg trade costs in my model, are quantitatively important components of this impact.

The structural change literature has largely found that the experience of countries is heterogeneous in that changing trade costs matters for some countries, and does not for others. My model, which features two stages of sequential production, two types of labor, and asymmetric trade costs, is able to account for salient features of India's economy and show that changes in trade costs were a key component of India's structural change experience in the 1990s and 2000s. Next steps will be expanding my counterfactual exercise to explain how much of India's structural change and skill premium growth can be explained by sector-biased productivity growth. Relative productivity growth in goods production mechanically has a similar effect on relative wages and sectoral reallocations of value added in my model as do import cost reductions. For this reason, I expect that sector-biased productivity growth favoring goods production will by itself explain a significant portion of India's structural change and skill premium growth. Once this effect is quantified, a more complete picture of India's structural change experience will emerge.

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A Appendix

A.1 Tariff Revenue

Tariff revenue consists of three components:

$$TR_i = TR_i^{consumption} + TR_i^{roundabout} + TR_i^{snake} \quad (34)$$

In the derivations that follow, let Λ_i^n denote the set of production paths for which country i is the stage- n producer. Additionally, define the consumer price index P_i^C :

$$P_i^C = \left[\sum_{s=1}^S \phi_i^s (P_i^s)^{1-\rho} \right]^{\frac{1}{1-\rho}} \quad (35)$$

The three components of tariff revenue can be expressed as follows:

$$TR_i^{consump.} = \sum_{s=1}^S \sum_{n=1}^I \sum_{\ell \in \Lambda_2^n} \pi_{\ell,i}^s \left[\phi_i^s \left(\frac{P_i^s}{P_i^C} \right)^{1-\rho} (w_i^h h_i + w_i^L u_i + TR_i) \frac{\tau_{ni}^s}{1 + \tau_{ni}^s} \right] \quad (36)$$

$$TR_i^{round.} = \sum_{s=1}^S \sum_{n=1}^I \sum_{\ell \in \Lambda_2^n} \pi_{\ell,i}^s \left[\sum_j \left(\left(\frac{1 - \gamma_i^j}{\gamma_i^j} \right) \psi_i^{s,j} \left(\frac{P_i^s}{P_i^{I,j}} \right)^{1-\rho_m} (w_i^h h_i^j + w_i^L u_i^j) \frac{\tau_{ni}^s}{1 + \tau_{ni}^s} \right) \right] \quad (37)$$

$$TR_i^{snake} = \sum_{s=1}^S (1 - \alpha_s) \sum_{n=1}^I \sum_{c=1}^I \sum_{\ell \in (\Lambda_1^n \cap \Lambda_2^i)} \pi_{\ell,c}^s \left(\frac{\tau_{ni}^s}{1 + \tau_{ni}^s} \right) \frac{1}{1 + \tau_{ic}^s} \times \\ \left[\phi_c^s \left(\frac{P_c^s}{P_c^C} \right)^{1-\rho} (w_c^h h_c + w_c^L u_c + TR_c) + \sum_j \left(\left(\frac{1 - \gamma_c^j}{\gamma_c^j} \right) \psi_c^{s,j} \left(\frac{P_c^s}{P_c^{I,j}} \right)^{1-\rho_m} (w_c^h h_c^j + w_c^L u_c^j) \right) \right] \quad (38)$$

where $TR_i^{consump.}$ denotes revenue from tariffs imposed on imports of stage-two varieties ultimately absorbed through final consumption, $TR_i^{round.}$ denotes revenue from tariffs imposed on stage-two varieties ultimately absorbed through roundabout production, and TR_i^{snake} denotes rev-

enue from tariffs imposed on stage-one varieties used as snake inputs.

A.2 Model-Implied Expenditure Flows

$$X_{ik}^{consumption,s} = \sum_{\ell \in \Lambda_2^i} \left[\pi_{\ell,k}^s \phi_i^s \left(\frac{P_k^s}{P_i^C k} \right)^{1-\rho} (w_k^h h_k + w_k^L \ell_k + T R_k) \right] \quad (39)$$

$$X_{ik}^{round,s} = \sum_{\ell \in \Lambda_2^i} \left[\pi_{\ell,k}^s \sum_j \left(\left(\frac{1 - \gamma_k^j}{\gamma_k^j} \right) \psi_k^{s,j} \left(\frac{P_k^s}{P_k^{I,j}} \right)^{1-\rho_m} (w_k^h h_k^j + w_k^L \ell_k^j) \right) \right] \quad (40)$$

$$X_{ik}^{snake,s} = (1 - \alpha_s) \sum_{n=1}^I \sum_{\ell \in (\Lambda_1^i \cap \Lambda_2^k)} \pi_{\ell,n}^s \left(\frac{1}{1 + \tau_{kn}^s} \right) \times \\ \left[\phi_n^s \left(\frac{P_n^s}{P_n^C} \right)^{1-\rho} (w_n^h h_n + w_n^L \ell_n + T R_n) + \sum_j \left(\left(\frac{1 - \gamma_n^j}{\gamma_n^j} \right) \psi_n^{s,j} \left(\frac{P_n^s}{P_n^{I,j}} \right)^{1-\rho_m} (w_n^h h_n^j + w_n^L \ell_n^j) \right) \right] \quad (41)$$

A.3 Model Mechanisms - Closed Economy Setting

Consider the environment outlined in Section 3, and suppose that iceberg trade costs are sufficiently high such that no trade occurs between the two nations ($\kappa_{12}^j, \kappa_{21}^j \rightarrow \infty \forall j \in \{G, S\}$). With all production paths being purely domestic, our two-stage becomes equivalent to a one-stage model, as productivity levels and factor intensities are assumed to vary by country and sector but not by production stage. In such a closed economy setting, it must be the case that consumption shares equal production shares. Therefore, Equation (23) must hold in our closed economy. Now, in contrast to our open economy example, only sector-biased productivity growth can drive structural change and a change in the skill premium. Equations (24) and (25) can then be rewritten:

$$\left(\frac{u_i}{h_i}\right)^{\frac{1-\rho}{\rho}} \left(\frac{T_i^G}{T_i^S}\right)^{\frac{1-\rho}{\rho\theta}} = \frac{\nu_i^S}{\nu_i^G} \quad (42)$$

$$\left(\frac{u_i}{h_i}\right)^{\frac{1}{\rho}} \left(\frac{T_i^G}{T_i^S}\right)^{\frac{1-\rho}{\rho\theta}} = \frac{w_i^H}{w_i^L} \quad (43)$$

Equation (34) demonstrates that relative productivity growth in the goods sector leads to an increase in the service sector value added share in country i . Regarding the skill premium, Equation (35) demonstrates that sector-biased productivity growth in the goods sector also leads to skill premium growth. Intuitively, complementarity between goods and services increases service sector expenditure and thus the value added share of services, which in turn leads to an increase in the relative return to the factor used intensively in service production, i.e. skilled labor.

A.4 Model Mechanisms - Derivation of Equation (26)

Recall Equation (25) in Section 3.1:

$$\frac{w_i^H}{w_i^L} = \left(\frac{u_i}{h_i}\right)^{\frac{1}{\rho}} \left[\left(\frac{T_i^G}{T_i^S}\right) \frac{\pi_{(i,i),i}^S}{\pi_{(i,i),i}^G} \right]^{\frac{1-\rho}{\rho\theta}}$$

Taking the log of each side and rearranging, we can write:

$$\ln \left(\frac{w_i^H}{w_i^L} \right) = C + \frac{\rho-1}{\rho\theta} \ln (\pi_{(i,i),i}^G) \quad (44)$$

where C is a constant. Now rewrite Equation (44) as follows:

$$\ln \left(\frac{w_i^H}{w_i^L} \right) = C + \frac{\rho-1}{\rho\theta} \ln \left(\frac{(c_i^G)^{-\theta} T_i^G}{\Theta_i^G} \right) \quad (45)$$

With two countries, there are four possible paths of production. Therefore, we have the following expression for Θ_i^G :

$$\begin{aligned}
\Theta_i^G = & (c_1^G)^{-\theta} T_1^G \\
& + [(c_1^G)^{1-\alpha_G} (c_2^G)^{\alpha_G} (\kappa^G)^{1-\alpha_G} \kappa_G]^{-\theta} (T_1^G)^{1-\alpha_G} (T_2^G)^{\alpha_G} \\
& + [(c_2^G)^{1-\alpha_G} (c_1^G)^{\alpha_G} (\kappa^G)^{1-\alpha_G}]^{-\theta} (T_2^G)^{1-\alpha_G} (T_1^G)^{\alpha_G} \\
& + [c_2^G \kappa^G] T_2^G
\end{aligned} \tag{46}$$

With symmetric countries, $T_1^G = T_2^G = T^G$ and $c_1^G = c_2^G = c^G$, and Equation (46) becomes:

$$\begin{aligned}
\Theta_i^G = & T^G (c^G)^{-\theta} [1 + (\kappa^G)^{-(2-\alpha_G)\theta} + (\kappa^G)^{-(1-\alpha_G)\theta} + (\kappa^G)^{-\theta}] \\
= & T^G (c^G)^{-\theta} \left[(\kappa_G^{-\theta(1-\alpha_G)} + 1) (\kappa_G^{-\theta} + 1) \right]
\end{aligned} \tag{47}$$

Combining Equations (47) and (45):

$$\ln \left(\frac{w_i^H}{w_i^L} \right) = D + \frac{1-\rho}{\rho\theta} \ln \left((\kappa_G^{-\theta(1-\alpha_G)} + 1) (\kappa_G^{-\theta} + 1) \right) \tag{48}$$

where D is a constant. Finally, the elasticity shown in Equation (26) can be calculated:

$$\begin{aligned}
\frac{\partial \ln \left(\frac{w_i^H}{w_i^L} \right)}{\partial \kappa^G} = & \frac{1-\rho}{\rho\theta} \left(\frac{-\theta \kappa_G^{-\theta-1}}{1 + (\kappa^G)^{-\theta}} + \frac{-\theta(1-\alpha_G) \kappa_G^{-\theta(1-\alpha_G)-1}}{1 + (\kappa^G)^{-\theta(1-\alpha_G)}} \right) \\
= & \frac{-(1-\rho)}{\rho \kappa_G} \left(\frac{1}{1 + (\kappa^G)^{\theta}} + \frac{1-\alpha_G}{1 + (\kappa^G)^{\theta(1-\alpha_G)}} \right)
\end{aligned} \tag{49}$$

A.5 Industry Concordance

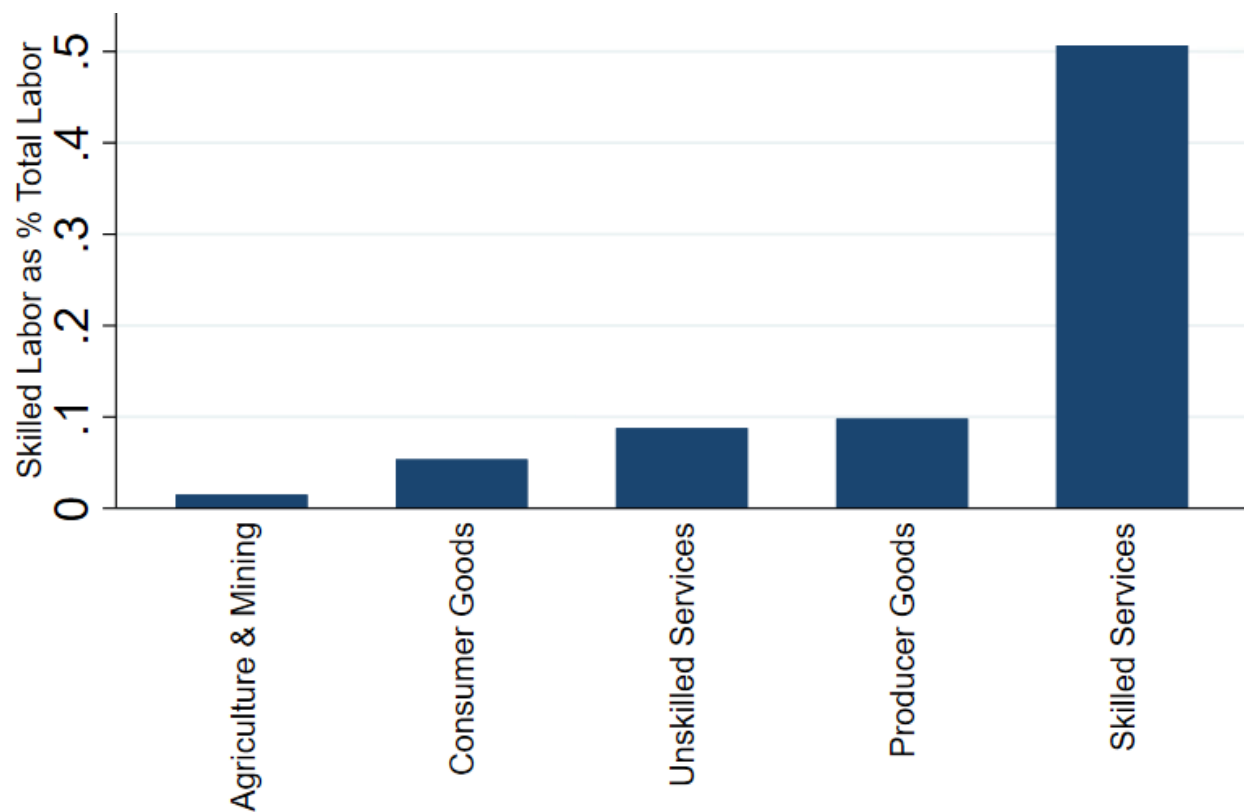
Industries in the WIOD tables are aggregated from the two-digit ISIC rev 3 level into five sectors.

The concordance between industry and sector is as follows:

- **Agriculture and Mining:** Agriculture, hunting, forestry, and fishing (AtB), Mining and quarrying (C)
- **Consumer Goods:** Food products, beverages, and tobacco (15-16), Textiles (17-19), Auto and other transport (34-35), Electrical, communication, medical (30-33), Other (36-37)
- **Producer Goods:** Machinery and equipment n.e.c. (29), Chemicals (24), Basic metals and metal products (27-28), Petroleum (23), Rubber and plastic products (25), Paper (21-22), Wood (20), Minerals (26)
- **Skilled Services** Real estate activities (70), Renting of machines and equipment and other business activities (71-74), Financial intermediation (F), Education (M), Health and Social Work (N)
- **Unskilled Services** Wholesale and Retail (50-52), Transport and Communication (60-64), Electricity (E), Construction (F), Hotels and Restaurants (H), Public Admin (L), Other Services (O)

A.6 Manufacturing Sector Classification - Consumer and Producer Goods

Figure 5: Skilled Labor Intensity by Sector in India, 1995-2005



Source(s): WIOD

A.7 Calculation of Tariff Rates

Tariff data is sourced from the World Bank World Integrated Trade Solution (WITS) database, using the methodology outlined by Mayer et al. (2023) in the construction of the CEPII Trade and Production Database. Specifically, MFN and preferential tariff rates are first calculated as the simple average rate at the HS 6-digit level. The minimum of these two is chosen, then HS 6-digit tariffs are mapped to ISIC Rev. 3 industries and aggregated into three goods sectors, taking simple averages.

A.8 Construction of Gross Output Price Deflators for Rest of World

As described in Section 4.5, cross-country gross output price deflators are sourced from the Productivity Level Database 2005 Benchmark (Inklaar and Timmer (2014), and within-country variation in sectoral price levels over time is sourced from the WIOD Socio Economic Accounts. For India and the United States, industry-level price deflators are aggregated into sectoral prices using annual industry shares of gross output as weights. For the rest of the world (RoW) aggregate, sectoral price deflators are imputed using constructed deflators for the 23 countries in the RoW grouping for which a full sequence of sectoral prices is available. Specifically, following Lee (2023), I construct annual gross output price deflators across all five sectors for each of these countries, then for each sector I regress log-prices on the log of GDP per capita with year fixed effects. The RoW price deflators are then imputed using the world average GDP per capita (excluding India and the United States) in each year.

A.9 Trade Cost Calibration

Proposition 1. Suppose that $\pi_{(i,i),j}^s$ is defined by Equation (16), and $\Pi_{i,j}^{F,s}$ by Equation (29). Then the following relationship must hold:

$$\frac{\pi_{(i,i),j}^s}{\pi_{(i,i),i}^s} = \frac{\Pi_{i,j}^{F,s}}{\Pi_{i,i}^{F,s}}$$

Proof. Fixing countries i and j , from the definition of $\pi_{(i,i),j}^s$ given by Equation (16), $\forall n \in I$:

$$\begin{aligned} \frac{\pi_{(n,i),i}^s}{\pi_{(n,i),j}^s} &= \frac{[(c_i^s)^{\alpha_s} (c_n^s)^{1-\alpha_s} (\kappa_{ni}^s)^{1-\alpha_s}]^{-\theta} (T_n^s)^{1-\alpha_s} (T_i^s)^{\alpha_s} \Theta_j^s}{[(c_i^s)^{\alpha_s} (c_n^s)^{1-\alpha_s} (\kappa_{ni}^s)^{1-\alpha_s} \kappa_{ij}^s]^{-\theta} (T_n^s)^{1-\alpha_s} (T_i^s)^{\alpha_s} \Theta_i^s} \\ &= \frac{\Theta_j^s}{(\kappa_{ij}^s)^{-\theta} \Theta_i^s} \end{aligned}$$

Thus, given $i, j \in I$:

$$\frac{\pi_{(n,i),i}^s}{\pi_{(n,i),j}^s} = \frac{\pi_{(k,i),i}^s}{\pi_{(k,i),j}^s} \quad \forall n, k \in I \quad (50)$$

Next, note that $\Pi_{i,j}^{F,s}$ can be written as follows:

$$\Pi_{i,j}^{F,s} = \sum_{n=1}^I \pi_{(n,i),j}^s \quad (51)$$

Then, by (44) and (45), the following holds:

$$\frac{\Pi_{i,j}^{F,s}}{\Pi_{i,i}^{F,s}} = \frac{\sum_{n=1}^I \pi_{(n,i),j}^s}{\sum_{n=1}^I \pi_{(n,i),i}^s} = \frac{\pi_{(i,i),j}^s}{\pi_{(i,i),i}^s} \quad (52)$$

A.10 Calibration

Figure 6: Calibrated Indian Import and Export Costs for Trade with ROW

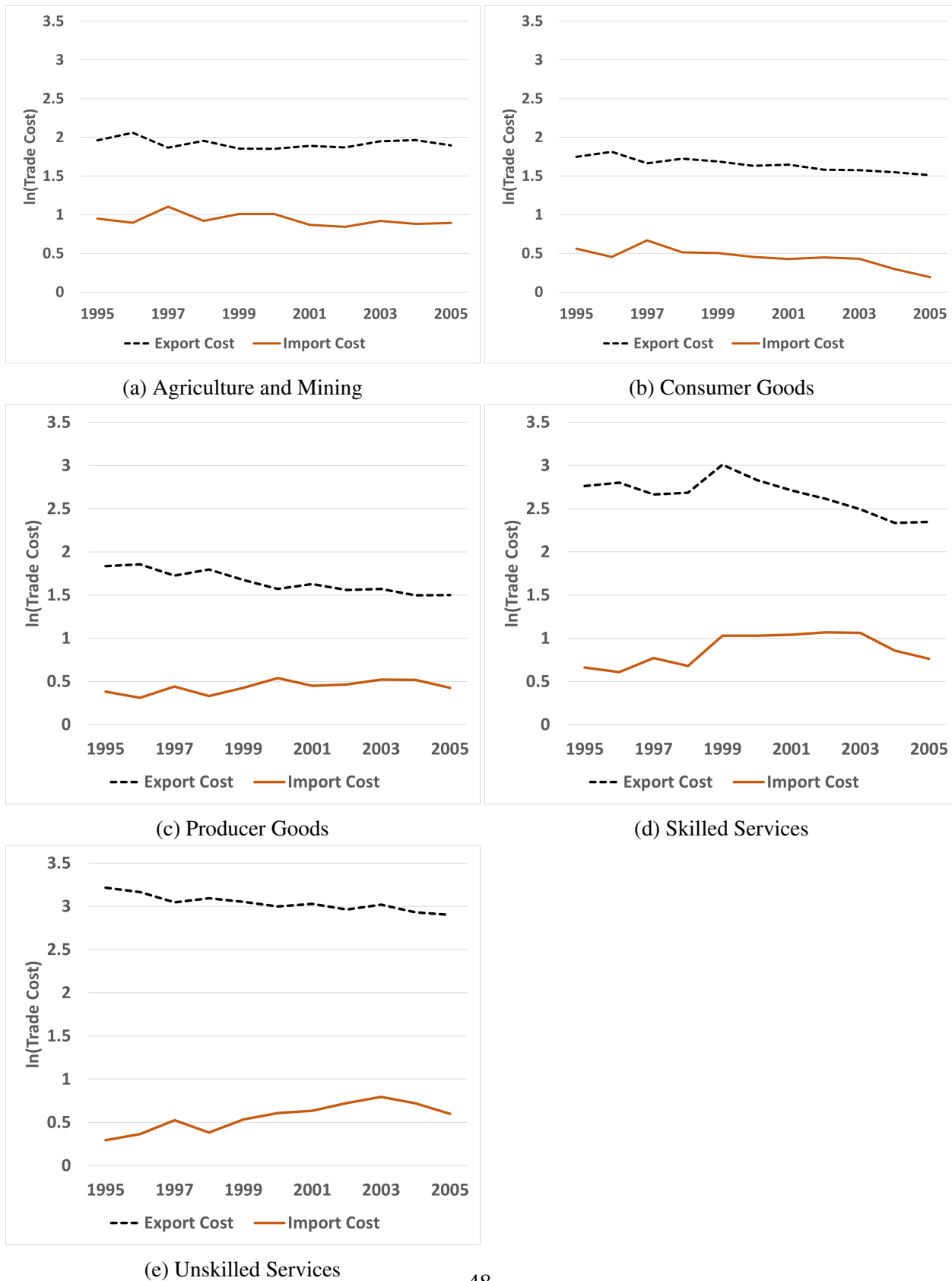
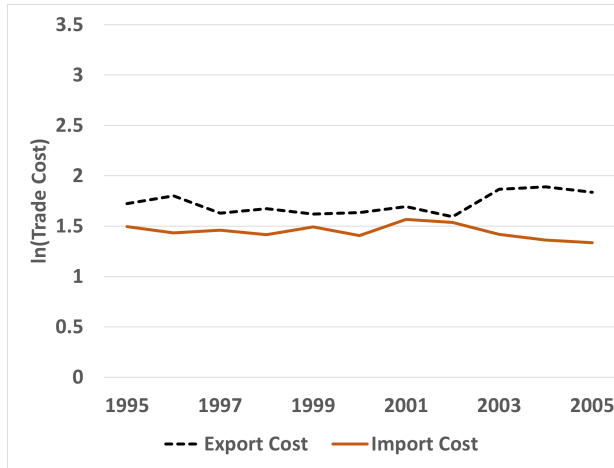
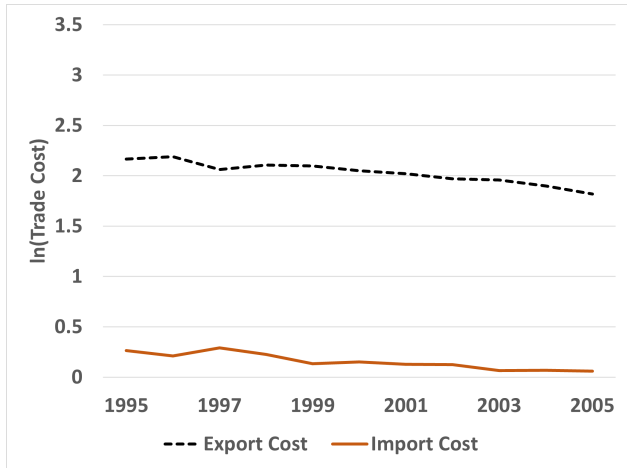


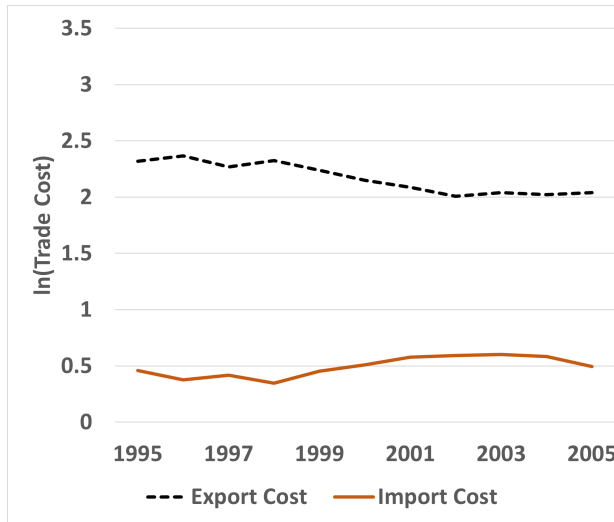
Figure 7: Calibrated Indian Import and Export Costs for Trade with U.S.



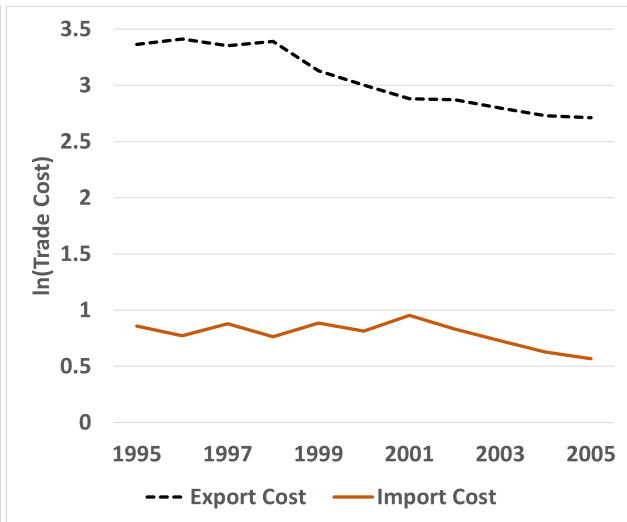
(a) Agriculture and Mining



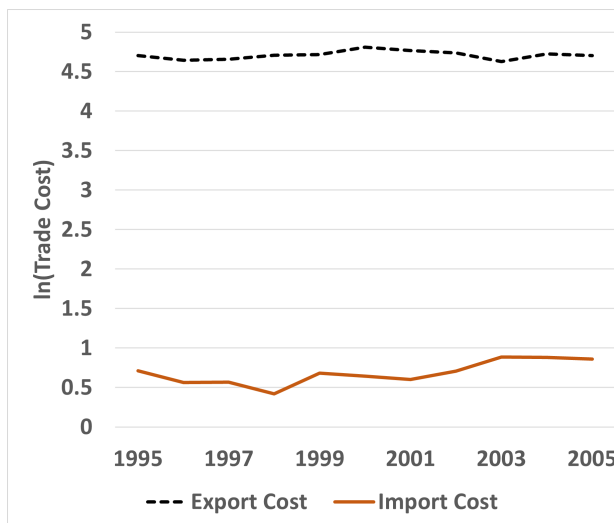
(b) Consumer Goods



(c) Producer Goods



(d) Skilled Services



(e) Unskilled Services

Table 7: Predetermined Parameters

Parameter(s)	Description	Value	Source
ρ_m^s	Elast. of subst. across inputs	.0001	Sotelo and Cravino (2019)
ρ	Elast. of subst. across sectors (consumption)	0.26	Comin et al. (2015)
$\theta^s = \theta$	Trade Elasticity	4	Simonovska and Waugh (2014)
σ	Elast. of subst. across labor types	1.48	Sotelo and Cravino (2019)
μ	Elast. of subst. across varieties	2	Standard in literature

Table 8: Labor Endowments

Country	L_i	$\frac{\bar{u}_i}{L_i}$	$\frac{\bar{h}_i}{L_i}$
IND	3.63	.95	.05
USA	1.00	.25	.75
RoW	9.61	.92	.08

Table 9: Calibrated ϕ_i^s

Country	ϕ_i^{Agr}	ϕ_i^{CG}	ϕ_i^{PG}	ϕ_i^{SS}	ϕ_i^{US}
IND	.06	.41	.27	.03	.24
USA	.01	.33	.18	.09	.40
RoW	.02	.37	.25	.08	.28

Table 10: Calibrated T_i^s

Country	T_i^{Agr}	T_i^{CG}	T_i^{PG}	T_i^{SS}	T_i^{US}
IND	.017	31	92	.06	1.45
USA	38	820	19100	33	620
RoW	40	1400	10400	52	115

Table 11: Calibrated α_s

α_{Agr}	α_{CG}	α_{PG}	α_{SS}	α_{US}
.20	.01	.001	.15	.15

Table 12: Calibrated β_i^s

Country	β_i^{Agr}	β_i^{CG}	β_i^{PG}	β_i^{SS}	β_i^{US}
IND	.94	.73	.68	.27	.70
USA	.63	.60	.63	.37	.66
RoW	.71	.66	.64	.29	.55

Table 13: Calibrated γ_i^s

Country	γ_i^{Agr}	γ_i^{CG}	γ_i^{PG}	γ_i^{SS}	γ_i^{US}
IND	.75	.25	.27	.79	.60
USA	.46	.31	.36	.66	.62
RoW	.60	.32	.36	.69	.56

Table 14: Calibrated ψ_i^s

Country	Sector s	$\psi_i^{s,Agr}$	$\psi_i^{s,CG}$	$\psi_i^{s,PG}$	$\psi_i^{s,SS}$	$\psi_i^{s,US}$
IND	Agriculture & Mining	.12	.03	.02	.00	.01
	Consumer Goods	.11	.33	.06	.29	.17
	Producer Goods	.60	.55	.84	.49	.67
	Skilled Services	.01	.01	.01	.03	.01
	Unskilled Services	.17	.09	.08	.19	.14
USA	Agriculture & Mining	.11	.03	.02	.01	.01
	Consumer Goods	.20	.50	.08	.17	.26
	Producer Goods	.58	.45	.85	.47	.56
	Skilled Services	.03	.01	.01	.15	.04
	Unskilled Services	.09	.02	.04	.21	.13
RoW	Agriculture & Mining	.08	.03	.02	.01	.02
	Consumer Goods	.23	.50	.06	.15	.19
	Producer Goods	.57	.42	.87	.52	.65
	Skilled Services	.02	.01	.01	.10	.03
	Unskilled Services	.11	.05	.04	.22	.12