Multinational Production, Intangible Capital, and Structural Change in the U.S.

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Abstract

This paper assesses the contribution of technological progress and increased degree of openness on the reallocation of sectoral value added in the U.S. using a two-country-two-sector dynamic model with multinational production (MP). I find that exogenous technological progress explained 85% of the decline in the measured value-added share of the goods sector in the U.S. from 1982 to 2012. If the model is recalibrated to abstract from multinational production, the impact of technological progress is underestimated by one percentage point, accounting for 10% of the observed decline in measured value-added share in the goods sector.

*University of International Business and Economics (UIBE), xiaohan.zhang@uibe.edu.cn This is one of the chapters in my doctorate dissertation at the University of Minnesota. I am indebted to my advisor and committee members for their guidance and support. I am also thankful to the participants of the Quantitative Macro Workshop at the University of Minnesota for their helpful feedback.

1 Introduction

From 1982 to 2012, goods sector employment in the U.S. declined by one-third. The debate on its driving forces is centered around differential sectoral productivity growth, income growth, and reducing trade barriers with the rest of the world. Specifically, estimation of consumer preference suggests that goods and services are complements and goods are necessities while services are luxuries (see, for instance, Herrendorf, Rogerson, and Valentinyi (2013)). Due to this feature of preference, the expenditure share on services increases as the goods sector productivity grows more rapidly than the service sector and as the aggregate income grows[1]. In a closed economy framework, a decline in expenditure share on goods translates into a decline in share of value-added of the goods sector. However, in an open economy, the expenditure share and the share of value-added differ by the sectoral net export. The share of value-added generated by the goods sector in a country with a comparative advantage in services (such as the U.S.) will fall along with the reduction of the trade barriers to goods and the income growth in the rest of the world. In an open economy, Kehoe, Ruhl, and Steinberg (2018) finds that the differential productivity growth accounts for 84% of the decline in the employment share of the goods sector in the U.S.

This project contributes to the debate on the driving forces for the decline of the share of the goods sector value-added by incorporating multinational production as another form of openness, which potentially implies alternative attribution for two reasons. First, part of the *measured* growth in sectoral TFP reflects multinational enterprises (MNEs) accumulation of intangible capital in response to reduced barriers to trade and FDI. MNEs invest in intangible capital that can be used non-rivalrously across locations. Without an explicit cost, the measured TFP of an affiliate increases due to R&D carried out by its parent, which a model that abstracts from multinational production cannot distinguish from exogenous technological progress in the country hosting the affiliate. Second, the gain from openness is different because MNEs can access the foreign market through FDI as an alternative to export. Trade flows, therefore, do not capture the full effect of openness and need to be supplemented by information embedded in the flows of FDI.

To quantify the impact of technological progress and increased degree of openness, I build a two-country, two-sector growth model where the country- and sector-specific representative firm is a multinational enterprise with stand-in plants in the U.S. and the rest of the world. The parents and the affiliates share the same stock of technology capital that can be non-rivalrously used across all plants. The parents invest in technology capital using their outputs and choose between export and FDI to serve the foreign market. Export is subject to country- and sector-specific iceberg costs. I model a country's policies governing its inbound FDI by an efficiency factor associated with the operation of the hosted affiliates. Households in both countries have a non-homothetic preference and consume goods and services as complements. Within the goods and service categories, consumers compose their bundles with home varieties, imported foreign varieties, and foreign varieties purchased from local affiliates through an Armington demand system. Labor supply is elastic and labor is perfectly mobile across all plants within the country borders. Households, as the owners, receive the dividends distributed by the MNEs and trade a risk-free bond.

I treat 1982 as a steady states and the transition with perfect foresight. The model is calibrated to data from the Bureau of Economic Analysis (BEA), World Input-Output Database (WIOD), and the Penn World Table. Between the two steady states, country- and sector-specific TFPs, iceberg costs, and openness to FDI are allowed to vary to match the changes in GDP per capita, goods sector employment share, bilateral trade flows, and FDI flows. To assess the impact of each wedge on employment share, I set all but one wedge at their values in 1982, and simulate forward counterfactual paths of the U.S. economy using the equilibrium conditions of the model. The resulted change in the share of goods sector value-added is interpreted as the contribution of the wedge allowed to fluctuate.

[1] The more rapid growth in goods sector productivity implies the relative price of goods (in terms of services) will fall

To highlight the role of multinational production, I recalibrated the TFPs and the trade costs in a restricted model where the multinational production channel is removed. With the values of the wedges inferred without the information related to MP, I do the same decomposition and compare with the baseline model the impact of changes in sectoral TFPs and trade costs on the decline of the share of value added of the goods sector.

I find that the main driving forces are the changes in sectoral TFPs. Together they account for an 8.5 percentage point decline in the share of value added of the goods sector. If the model is recalibrated to abstract from multinational production, the share of goods sector value added decreases by 9.5 percentage points following the changes in the TFPs. The difference of one percentage points accounts for 10% of the observed decline in the value-added share of the goods sector. One reason that my results differ from those in Kehoe, Ruhl, and Steinberg (2018) is that in my framework, part of the decline of goods sector value added driven by TFP growth in Kehoe, Ruhl, and Steinberg (2018) is attributed to an increased degree of openness through MNEs' investment in nonrivalrous technology capital.

Related Literature This project extends the framework in McGrattan and Prescott (2010); McGrattan and Waddle (2020) to a multi-sector environment and studies the interaction of firms' investment and the trade and MP structures as a channel that generates the observed changes in the relative prices of goods and services. It contributes to the literature of structural change in closed or open economies (see, for instance, Kongsamut, Rebelo, and Xie (2001); Ngai and Pissarides (2007); Buera and Kaboski (2009); Duarte and Restuccia (2010); Herrendorf, Herrington, and Valentinyi (2015); Duarte and Restuccia (2020); Uy, Yi, and Zhang (2013); Kehoe, Ruhl, and Steinberg (2018); Sposi (2019); Sposi, Yi, and Zhang (2021)), by taking into account MP and endogenous investment in technology capital.

This project also contributes to the literature of MP pioneered by Ramondo and Rodríguez-Clare (2013) and Helpman, Melitz, and Yeaple (2004) and later application on structural change by Alviarez et al. (2022). In particular, I allow firm's investment be affected by their anticipation for future changes in the economic environment, which is missing in the classic frameworks where the the models are static.

The project also relates to the literature on the labor impact of international trade David, Dorn, and Hanson (2013); Autor, Dorn, and Hanson (2016); Caliendo, Dvorkin, and Parro (2019). Instead of focusing on the import competition from China in the 2000s, this paper models the rest of the world by the U.S. main trade partner and uses the income level and sectoral employment share in the rest of the world to infer the productivity levels.

Layout of the paper In the remaining of the paper, Section 2 presents the trends in data of sectoral value-added, trade, and direct investment in the U.S. I lay out the model and the accounting procedure in Section 3 and Section 4, respectively. Section 5 describes the calibration of parameters and the level of wedges in the nonstochastic steady state, as well as the estimation strategy of the parameters in the stochastic process. Section 6 reports the main results. Section 7 concludes.

2 Data

I use data from WIOD to document the decline of the share of value-added in the goods sector in the U.S.

TREND 1: The measured share of value-added of U.S. goods sector declined by one third. As is shown in Figure 1, in 2014, the

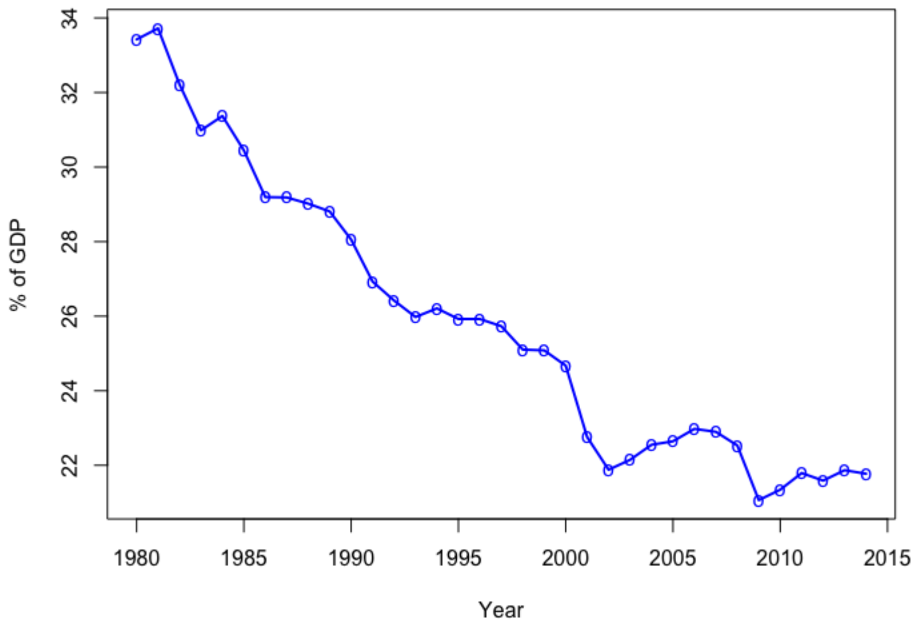

Figure 1: Value-Added of the Goods Sector in the U.S.

TREND 2: U.S. has revealed comparative advantage in the service sector. As is shown in Figure 2 and Figure 3, during the time period, U.S. has been a net importer of value-added produced by the goods sector and a net exporter for the service sector.

TREND 3: As fractions of sectoral value-added, direct investment increased over the years in both sectors in the U.S. (see Figure 4)

3 The Model

This section presents a two-country dynamic general equilibrium model of MP and trade of sectoral value added between the U.S. and RW. The model extends the framework in McGrattan and Prescott (2010) and McGrattan and Waddle (2020) by incoporating multiple sectors and nonhomothetic preference. I will first describe the model environment, and then the optimization problems faced by the firms and the households in each country. Finally, I construct momdel moments as measured in the national accounts and discuss what is captured (and missed) by those statistics.

3.1 Environment

There are two countries, the U.S. and the rest of the world (RW), and time is discrete. We use $i, j \in \{u, r\}$ to index the countries. A country is a measure of homogeneous locations where firms can set up operations. Denote by N_i the number of locations in country i. We assume N_i is equal to a country's population up to a scaler to capture that a retail chain can set up more franchises in a large country than in a small one. Without loss of generality, let the scaler be one.

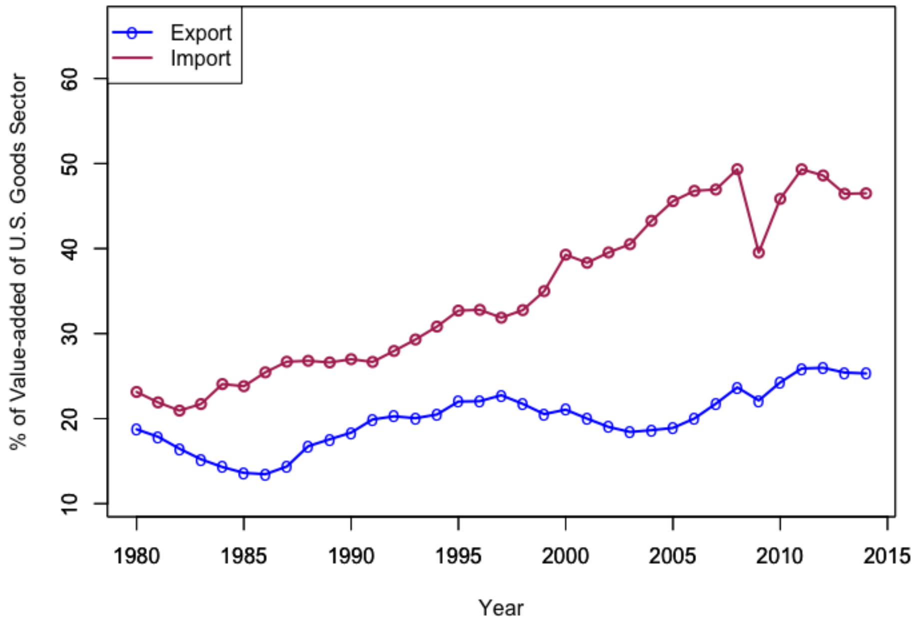

Figure 2: Trade in Value-Added of the Goods Sector in the U.S.

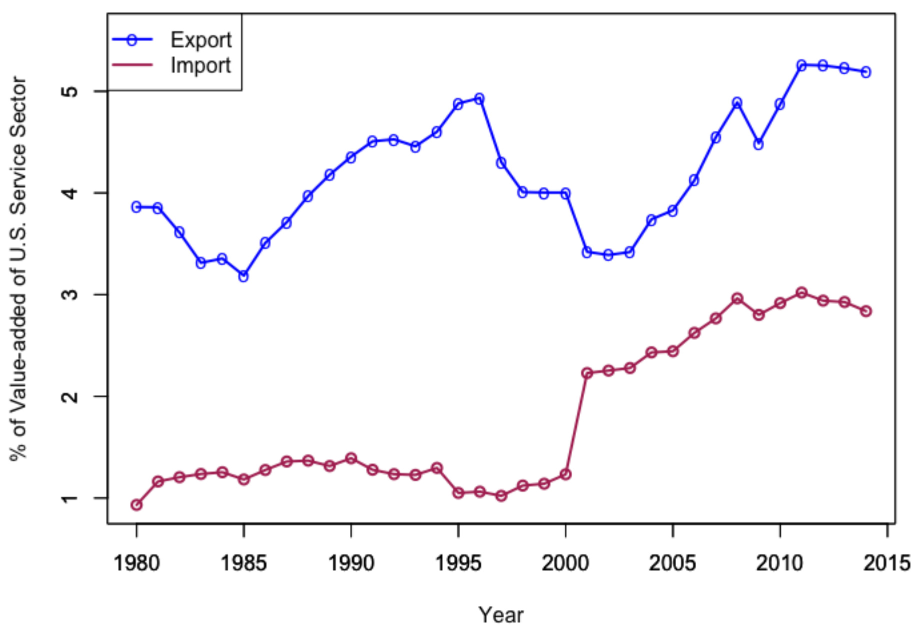

Figure 3: Trade in Value-Added of the Service Sector in the U.S.

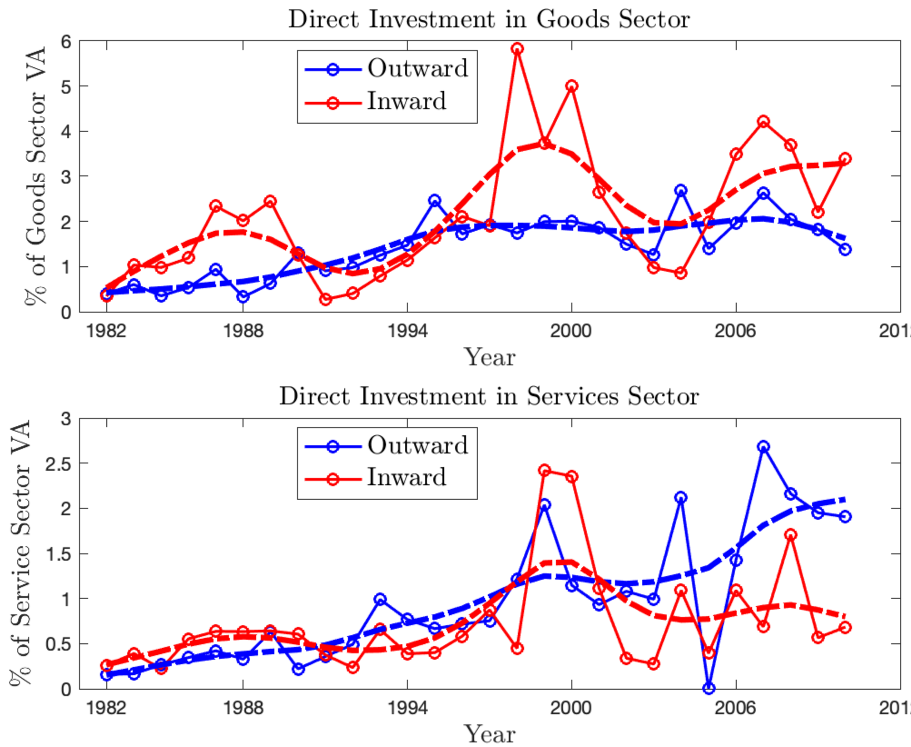

Figure 4: Direct Investment in Goods and Service Sectors

Technology Each country has a goods and a service sector. A sector is indexed by $l \in \{g, s\}$. In each sector, a representative producer, indexed by the sector and its country of origin, il, owns a stock of technolgoy capital, by which we capture the the sectorwide blueprints, brandnames, and organizational capital, etc. In each location in country i, one unit of technology capital, when combined with location-specific input, denoted by z_i, produces a country- and sector- specifiic variety via

$$\sigma_i^{jl} A_i^l \cdot z_i^{1-\phi}$$

where A_i^l denotes the TFP of sector l in country i, capturing the rule of law, average human capital, and other factors that affect a firm's efficiency and are not subject to firms' choices. σ_i^{jl} represents the differential government regulation faced by a domestic and a foreign-owned (by country j) business in sector l country i. If a plant is owned by a domestic firm, σ_i^{il} is normalized to one. σ_i^{jl} characterizes country i's openness to FDI in sector l. We take A_i^j and σ_i^{jl} as exogenous wedges as in Chari, Kehoe, and McGrattan (2007). The location-specific input is modeled as a Cobb-Douglass composite of tangible capital, plant-specific intangible capital, and labor,

$$z_i = k_{T,i}^{\alpha_1} \cdot k_{I,i}^{\alpha_2} \cdot h_i^{1-\alpha_1-\alpha_2}$$

While k_T captures standard physical capital such as equipments and structures, examples of plant-specific intangible capital, k_I, include a firm's acquaintance of the business environment, as well as its accumulation of local client list and non-compete agreement, etc. At each location, the production technology has decreasing return to scale, $\phi \in (0, 1)$, by which a plant has a finite span of control.

The technology capital has nonrivalrous use across a firm's operations in different locations. Because of this feature of nonrivalry, a firm will employ its technology capital in its entirety at each production location, home and abroad. This give rise to a structure of horizontal multinational production. Let M^{jl} denote the stock of technology capital owned by firm jl. With the assumption that the locations are homogeneous within a country and the technology of decreasing-return-to-scale, a firm will choose the same amount of location-specific input for each unit of technology capital at each location. The total value added firm jl produces in country i is thus

$$\sigma_i^{jl} A_i^l N_i M^{jl} \left(z_i^{jl}\right)^{1-\phi}$$

Let $Z_i^{jl} \equiv N_i M^{jl} z_i^{jl}$ denote the total location-specific factors firm jl employs in country i. Then its aggregate production function in country i is

$$\sigma_i^{jl} A_i^l \left(N_i M^{jl}\right)^{\phi} \left(Z_i^{jl}\right)^{1-\phi}$$

The output produced by jl in country j can be shipped to foreign subject to an iceberg cost, τ_i^{jl}.[2] In order for one unit of output to arrive in country i, τ_i^{jl} units have to be shipped, and $\tau_i^{jl} - 1$ units melt along the shipment. τ_i^{jl} captures tariff and non-tariff based trade frictions, and characterizes a country's openness to trade in sector l.

In a spirit similar to the remarks in Herrendorf, Rogerson, and Valentinyi (2013), the trade in value added (rather than the trade of merchandises and services) is artificial. For instance, when the U.S. imports a bag of bread, in the view of trade of merchandise and services, the bread is counted as imported goods by the U.S. However, in the framework of trade of value added, U.S. imports value added from the goods sector (agriculture, manufacturing) and the service sector (distribution service such as wholesale trade) in RW. Moreover, compared to a closed-economy framework, additional consideration of trade in intermediate input needs to be accounted: the value added embedded in imported intermediate input in a country's export is excluded from the flow of exports. In our example, if the bread is made of flour RW imported from the U.S., then the import by U.S. we consider is the bread without flour, that is, only the knitting produced by the goods sector and distribution service are counted as imports by the U.S.

The production factors are assumed to be freely mobile across locations, with the exception that labor is immobile between the two countries.

Preference There are N_i homogeneous stand-in households in country i. In each period, a household is endowed with one unit of time to be spent in work and leisure. Let the household's preference over consumption and leiure be standard and admit a balanced growth path. Here, I assume $u\left(c_i, 1-h_i\right) = \ln\left(c_i\right) + \psi \ln\left(1-h_i\right)$, where h_i is the hours worked, and c_i is the household's consumption of value added produced by the goods and the service sectors composited through,

$$\begin{aligned} c_i &= c_i\left(c_i^g, c_i^s\right) \\ &= \left[\omega_i^{\frac{1}{\zeta}}\left(c_i^g + \bar{c}_i^g\right)^{\frac{\zeta-1}{\zeta}} + \left(1-\omega_i\right)^{\frac{1}{\zeta}}\left(c_i^s + \bar{c}_i^s\right)^{\frac{\zeta-1}{\zeta}}\right]^{\frac{\zeta}{\zeta-1}} \end{aligned}$$

as in Herrendorf, Rogerson, and Valentinyi (2013). As is standard, ω is a nonnegative weight and $\bar{c}^l, l \in \{g, s\}$ are constant. When $\zeta \to 1$ we recover the Stone-Geary type of preference used in Kongsamut, Rebelo, and Xie (2001). When $\bar{c}^g = \bar{c}^s = 0$, the preference is the standard CES preference used in Ngai and Pissarides (2007).

To see how the relative expenditure shares on goods and services respond to changes in price and income, consider the the static optimization problem where the household takes the prices and consumption expenditure

[2] I asumed away the shipment from subsidiaries to parents, which is quantitatively small (about 5% of total sales of subsidiaries and 10% of U.S. import.

as given. Let p_i^l denote the price of sector l and p_i the price of the composite consumption in country i that a hypothetical aggregator producing c_i form c_i^g and c_i^s makes zero profit.[3]

$$\max\ c_i\left(c_i^g, c_i^s\right)$$
$$\text{s.t. } p_i^g c_i^g + p_i^s c_i^s = p_i c_i$$

For simplicity of illustration, consider a special case where $\bar{c}^g = 0$ and $\bar{c}^s > 0$ and the solution is interior. From the FOCs,

$$\frac{p_i^g c_i^g}{p_i c_i} = \frac{\omega\left(p_i^g\right)^{1-\zeta}}{\omega_i\left(p_i^g\right)^{1-\zeta} + \left(1-\omega_i\right)\left(p_i^s\right)^{1-\zeta}}\left(1 + \frac{p_i^s \bar{c}_i^s}{p_i c_i}\right)$$
$$\frac{p_i^s c_i^s}{p_i c_i} = \frac{\left(1-\omega_i\right)\left(p_i^s\right)^{1-\zeta}}{\omega_i\left(p_i^g\right)^{1-\zeta} + \left(1-\omega_i\right)\left(p_i^s\right)^{1-\zeta}}\left(1 + \frac{p_i^s \bar{c}_i^s}{p_i c_i}\right) - \frac{p_i^s \bar{c}_i^s}{p_i c_i}$$

it is straitforward to see that when the prices are held constant and c increases, the expenditure share on goods (services) decreases (increases). This illustrates the income effect inttroduced by $\bar{c}^s > 0$. To see how relative expenditure responds to changes in relative price when consumption expenditure is fixed, consider an increase in p^s while p^g is held constant. From

$$\frac{p_i^s c_i^s}{p_i^g c_i^g} = \left(1 + \frac{p_i^s \bar{c}_i^s}{p_i c_i}\right)^{-1}\left[\frac{1-\omega_i}{\omega_i}\left(\frac{p_i^s}{p_i^g}\right)^{1-\zeta} - \frac{p_i^s \bar{c}_i^s}{p_i c_i}\right]$$

we see that when $\bar{c}^s > 0$, the relative expenditure is less responsive to changes in relative prices than in the case where $\bar{c}^s = 0$. To what extent the reponse is dampened is controled by $\bar{c}^s$, the same factor governing the strength of income effect. However, the direction of changes is the same as long as $1 + \frac{p_i^s \bar{c}_i^s}{p_i c_i} > 0$. That is, when $\zeta < (>)\, 1$, goods and services are gross complements (substitutes).

Within each sector, a household consumes a CES composit of home and foreign varieties,

$$c_i^l = \left[\left(c_i^{il}\right)^{\frac{\rho-1}{\rho}} + \left(c_i^{jl}\right)^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}}$$

where the foreign variety can be obtained through trade and FDI,

$$c_i^{jl} = \left[\left(c_i^{jl,T}\right)^{\frac{\varrho-1}{\varrho}} + \left(c_i^{jl,D}\right)^{\frac{\varrho-1}{\varrho}}\right]^{\frac{\rho}{\rho-1}}$$

An example of this nested CES is that a U.S. household consume two cars, one from Ford and the other from BMW. The household can purchase the BMW car from a BMW subsidiary in the U.S. or have it shipped from Germany. Within a sector, trade and MP serve as substitute for consumers to obtain the foreign variety.

3.2 Dynamic Optimization

To describe the dynamic choices faced by firms and households, let $s_t \equiv \{A_{ut}^g, A_{ut}^s, A_{rt}^g, A_{rt}^s, \sigma_{ut}^{rg}, \sigma_{ut}^{rs}, \sigma_{rt}^{ug}, \sigma_{rt}^{us}, \tau_{ut}^{rg}, \tau_{ut}^{rs}, \tau_{rt}^{ug}, \tau_{rt}^{us}\}$ denote the stochastic variables we take as exogeneous, and let $\pi\left(s_t\right)$ be the (unconditional) probablity of the real-

[3] It can be shown that

$$p_i^{1-\zeta} = \frac{\omega_i\left(p_i^g\right)^{1-\zeta} + \left(1-\omega_i\right)\left(p_i^s\right)^{1-\zeta}}{1 + \frac{p_i^s \bar{c}_i^s}{p_i c_i}}$$

Note that p_i increases as $p_i c_i$ increases.

ization of state s_t.

Frim Each multinaltional producer maxizes the present discounted value of global divdidends and uses the Arrow-Debrew price, $\mu(s_t)$, as discount factor. In each period, the parent firm chooses the level of output and employment and invest in tangible capital, country-specific intangible capital, and the technology capital with nonrivalrous usage across locations, of which I assume the expense is undertaken by the parent firm. Note that the parent firm also chooses the amount of export, which is not explicitly shown because in equilibrium, the marginal revenues from selling domestically or abroad are equalized.

$$\max_{\left\{H_{it}^{il}(s_t),K_{Tit+1}^{il}(s_t),K_{Iit+1}^{il}(s_t),M_{t+1}^{il}(s_t)\right\}_{t\geq 0}} \sum_{t=0}^{\infty}\sum_{s_t|s_{t-1}} \mu_t^i(s_t)\, D_{it}^{il}(s_t)$$

$$\begin{aligned} D_{it}^{il}(s_t) =& p_{it}^{il}(s_t)\Big\{Y_{it}^{jl}(s_t) - K_{T,it+1}^{il}(s_t) + (1-\delta_T)\, K_{T,it}(s_t) \\ & -K_{I,it+1}^{il}(s_t) + (1-\delta_I)\, K_{Iit}^{il}(s_t) - M_{t+1}^{il}(s_t) + (1-\delta_M)\, M_t^{il}(s_t)\Big\} \\ & - w_{it}(s_t)\, H_{it}^{il}(s_t) \\ Y_{it}^{jl}(s_t) =& A_{it}^{l}(s_t)\left(N_{it}M_t^{il}(s_t)\right)^{\phi}\left(\left(K_{Tit}^{il}(s_t)\right)^{\alpha_1}\left(K_{Iit}^{il}(s_t)\right)^{\alpha_2}\left(H_{it}^{il}(s_t)\right)^{1-\alpha_1-\alpha_2}\right)^{1-\phi} \end{aligned}$$

In each period, the subsidiary taking the stock of technology capital as given chooses the level of output and employment, and invests in tangible capital and location-specific intangible capital.

$$\max_{\left\{H_{jt}^{il}(s_t),K_{T,jt+1}^{il}(s_t),K_{I,jt+1}^{il}(s_t)\right\}_{t\geq 0}} \sum_{t=0}^{\infty}\sum_{s_t|s_{t-1}} \mu_t^i(s_t)\, D_{jt}^{il}(s_t)$$

$$\begin{aligned} D_{jt}^{il}(s_t) =& p_{jt}^{il}(s_t)\left\{Y_{jt}^{il}(s_t) - K_{T,jt+1}^{il}(s_t) + (1-\delta_T)\, K_{T,jt}^{il}(s_t)\right. \\ & \left. -K_{I,jt+1}^{il}(s_t) + (1-\delta_I)\, K_{I,jt}^{il}(s_t)\right\} - w_{jt}(s_t)\, H_{jt}^{il}(s_t) \\ Y_{jt}^{il}(s_t) =& \sigma_{jt}^{il}A_{jt}^{l}(s_t)\left(N_{it}M_t^{il}(s_t)\right)^{\phi}\left(\left(K_{Tjt}^{il}(s_t)\right)^{\alpha_1}\left(K_{Ijt}^{il}(s_t)\right)^{\alpha_2}\left(H_{jt}^{il}(s_t)\right)^{1-\alpha_1-\alpha_2}\right)^{1-\phi} \end{aligned}$$

Household Households maximize utility by choosing consumption and leisure and trading a state-dependent bond with the other country. Labor is mobile between sectors and across plants within a country.

$$\max_{\left\{c_{it}(s_t),h_{it}(s_t),b_{it+1}(s_t),\left(s_{ijt}^{il}(s_t)\right)_{j,l}\right\}} \sum_{t=0}^{\infty}\sum_{s_t}\beta^t\pi(s_t)\, u\left(c_{it}(s_t), h_{it}(s_t)\right)$$

$$s.t.$$

$$\begin{aligned} \left(\mu_t^i(s_t)\right) \qquad p_{it}(s_t)\, c_{it}(s_t) \leq& w_{it}(s_t)\, h_{it}(s_t) + b_{it+1}(s_t) - \left(1 + r_t^b(s_t)\right) b_{it}(s_t) \\ & + \sum_{l\in\{\text{g, s}\}}\sum_{j\in\{\text{u, r}\}} \text{shr}_{ijt}^{il}(s_t)\left(V_{jt}^{il}(s_t) + d_{jt}^{il}(s_t)\right) \\ & - \sum_{l\in\{\text{g, s}\}}\sum_{j\in\{\text{u, r}\}} \text{shr}_{ijt+1}^{il}(s_t)\, V_{jt}^{il}(s_t) \end{aligned}$$

3.3 Market Clearance

In equilibrium, the output of the parents of a MNE is used for domestic consumption, exported for foreign consumption, invested in its location-specific capitals, and invested in the non-rivalrous intangible capital. The output produced by the affiliates is used for the consumption in the hosting country and the investment in its location-specific capital.

$$Y_{it}^{il}\left(s_t\right) = C_{it}^{il}\left(s_t\right) + \tau_{jt}^{il}\left(s_t\right) C_{jt}^{il,T}\left(s_t\right) + X_{Tit}^{il}\left(s_t\right) + X_{Iit}^{il}\left(s_t\right) + X_{Mt}^{il}\left(s_t\right)$$

$$Y_{jt}^{il}\left(s_t\right) = C_{jt}^{il,F}\left(s_t\right) + X_{Tjt}^{il}\left(s_t\right) + X_{Ijt}^{il}\left(s_t\right)$$

In equilibrium, the price index for each sector is

$$p_{it}^{l}\left(s_t\right) = \left[\sum_{j=u,r}\left(p_{it}^{jl}\left(s_t\right)\right)^{1-\rho}\right]^{\frac{1}{1-\rho}}$$

where

$$p_{it}^{jl}\left(s_t\right) = \tau_{it}^{jl}\left(s_t\right) p_{it}^{il}\left(s_t\right)$$

$$p_{it}^{jl}\left(s_t\right) = \left[\left(p_{it}^{jl,T}\left(s_t\right)\right)^{1-\varrho} + \left(p_{it}^{jl,D}\left(s_t\right)\right)^{1-\varrho}\right]^{\frac{1}{1-\varrho}}$$

In equilibrium, the state-dependent bond has zero net supply,

$$B_{ut}\left(s_t\right) + B_{rt}\left(s_t\right) = 0,$$

where $B_{it}\left(s_t\right) \equiv N_{it} b_{it}\left(s_t\right)$, and the labor market in each country clears,

$$\sum_{l=g,s}\sum_{j=u,r} H_{it}^{jl}\left(s_t\right) = h_{it}\left(s_t\right) N_{it}$$

3.4 Map to BEA Accounts

For each sector l, the value-added is the sum of value-added across all plants within the sector, regardless of the plant's country of origin. Note that although BEA started to capitalize R&D and software as intangible investment since the 2013 revision, there is still nontrivial expenditure other than these two categories that are expensed (e.g. advertising), and intangible investment are not capitalized in the international accounts in BEA. Therefore, I treat the intangible investment excluded from the measured statistics in the national accounts.

- value added by sector

$$\begin{aligned}\mathrm{VA}_{it}^{l} =& p_{it}^{il}\left(s_t\right)\left(Y_{it}^{il}\left(s_t\right) - X_{Iit}^{il}\left(s_t\right) - X_{Mt}^{il}\left(s_t\right)\right)\\ &+ p_{it}^{jl}\left(s_t\right)\left(Y_{it}^{jl}\left(s_t\right) - X_{Iit}^{jl}\left(s_t\right)\right)\end{aligned}$$

- import by sector and country

$$\mathrm{IMP}_{it}^{jl} = p_{it}^{jl}\left(s_t\right)\tau_{it}^{jl}\left(s_t\right) C_{it}^{jl,T}\left(s_t\right)$$

- inbound FDI by sector and country

$$\mathrm{DI}_{it}^{l} = p_{it}^{jl}\left(s_t\right) X_{Tit}^{jl}\left(s_t\right)$$

3.5 Discussion

Resources are reallocated between two sectors and home and foreign owned business by the change of relative prices, which are in turn, driven by the wedges A, σ, τ. They all entered the environment as productivities. Aside from the direct effect, the interactions associated with assumptions in this projects are also main channels through which the exogenous stochastic wedges come into effect.

Interaction between Trade and FDI in Multisector Models Within a sector, direct investment acts as a substitute to export to access the foreign market. When a host country becomes more open towards FDI in sector l, the country imports less in sector l. Between sectors, however, direct investment and trade may be complement/substitute depending on the elasticity of substitution between sectoral consumption. For instance, when a country lowers its trade barrier to imported goods, goods price decreases, and higher expenditure is directed to services. Since services are less tradable than goods, higher demand of services attracts more inward direct investment in the service sector.

Price response to lower trade barriers Although U.S. per capita income is much higher than that in RW, at the aggregate level, U.S. demand is relatively small. As the income grows in RW, RW demands more of services. When there is only trade, services of the U.S. variety can only be produced in the U.S. and the price has to jump drastically due to its scarcity. When there is MP, the impact is dampened, because thanks to the nonrivalry of technology capital, production can be scaled up in a large market to meet elevated demand.

Measurement of intangible capital Part of the change in measured productivity is endogenous. Not capitalizing the intangible capital causes time-varying mismeasurement of sectoral productivity.

4 Accounting Procedure

In this section, I explain the accounting procedure by which I isolate the marginal impact of each wedge and the combination of the wedges on the share of measured value added of the goods sector in the U.S. and the other aggregate variables. To isolate the marginal effect of, say, the efficiency wedges, I hold all the other wedges at constant values during the sample periods and keep the probability distribution of the efficiency wedges the same as that when all wedges are allowed to fluctuate. In effect, this ensures that the agents' expectations of the future evolvement of the efficiency wedges unchanged conditional on the states. The implied changes of the value added of the goods sector are compared with data and the path implied by the same experiment in the trade-alone economy.

Suppose the stochastic process $\pi(s^t)$ and the state s^t are known over the sample period. Recall that the wedges are functions of the underlying state s^t. So when s^t is known, $A(s^t)$, $\sigma(s^t)$, and $\tau(s^t)$ are known. To study the marginal impact of the efficiency wedge, I consider an economy with the same $\pi(s^t)$ and the same functions of $A(s^t)$ but the other wedges set to be constant functions, i.e., $\sigma(s^t) = \bar{\sigma}$ and $\tau(s^t) = \bar{\tau}$. Then I compute the associated equilibrium outcomes in this economy and compare them with the data counterparts. Similarly, I study the impacts of the wedges of trade cost and distortions over direct investment. By comparing the paths implied by a particular set of wedges with the actual path in the data, I decompose by different driving forces the decline of the value-added share of the goods sector in the U.S. Recall that with all wedges allowed to fluctuate, the model reproduces the actual path in data.

In practice, neither the stochastic process nor the states are observable and need to be estimated from data. To do so, I impose the same assumptions that the process of s_t is Markovian and the wedge functions are bijections, as in Chari, Kehoe, and McGrattan (2007).

Equipped with the two assumptions, I estimate the parameters of the Markov process using the maximum likelihood method. For now, these parameters are set a priori as in Table 2. Next, I uncover the event s^t by measuring the realized wedges. Because of the unobservability of intangible investment and the MP structure, the wedges cannot be separately calculated from data. Instead, I back out the wedges using the measurement equations in the Kalman filter. The measurement equations are those that express the statistics of value added, import, and inbound direct investment flows by country and sector in the state variables. In measuring the realized wedges, the estimated stochastic process plays a role. In the current version, I took the persistence and variance parameters of the stochastic process from literature.

The third step in to isolate the marginal effect of the efficiency wedges. In particular, starting from the initial values of k_T, k_I, and M, I use the series of s_t, the policy functions, as well as the laws of motion of capital to compute the evolvment of value added of the goods sector in the U.S. The changes during the period is the efficiency wedge component of the decline of goods sector value added.

5 Calibration and Estimation

5.1 Parameterization of the nonstochastic steady state

In this section, I describe the parameterization of the nonstochastic steady state which I calibrate to align with the U.S. economy in 1982. I first explain the parameters and then the mean of the wedges. The parameters with fixed values overtime are summarized in Table 1.

Table 1: Parameters with Values Fixed Overtime

Pre-determined parameters			
elasticities of substitution	ρ	Simonovska-Waugh (2014)	4
	ϱ	robustness check	15
	ζ	Herrendorf et al. (2013)	1.2
Calibrated parameters			
population	N_{u1982}, N_{r1982}	RoW pop/U.S. pop	1, 7.1
non-homotheticity	$\bar{c}^g, \bar{c}^s$	$\frac{p\bar{c}}{C}$ in Herrendorf et al. (2013)	0, 0
disutility of labor	ψ	$\frac{1}{3}$ of hours in labor	1.4
non-rivalrous intangible capital	ϕ, δ_M	U.S. annual expenditure in R&D and advertising	0.07, 0.08
plant-specific intangible capital	α_I,δ_I	market value of corporate values	0.07, 0
plant-specific tangible capital	$(1-\phi)\alpha_T$	capital to output ratio	0.23
	δ_T	investment to stock of capital	0.06

5.2 Estimation of the matrices of stochastic process

To apply the accounting procedure specified in Section 4, I first specify a vector autoregressive $AR(1)$ process for the exogenous stochastic state variables,

$$s_{t+1} = P_0 + Ps_t + Q\varepsilon_t$$

$$\varepsilon_t \sim \mathcal{N}(0, I),$$

where the shock ε_t, is independent and identically distributed over time and is assumed to follow the standard normal distribution. Let Q be the lower triangular matrix sunch that $V = QQ'$. Q is estimated instead of V to ensure that V is positive definite. For now, P is a diagonal matrix whoes the diagonal elements govern the persistence of the process.

I then use the maximum likelihood method to estimate the elements of P_0, P, and Q of the vector $AR(1)$ process for the wedges. In doing so, I linearize the economy around the steady state of the modeled economy, as well as data moments on value added, trade flows, and direct investment flows.

Table 2: Parameters with Values Fixed Overtime

Correlation coefficients		
$P_A = \begin{bmatrix} 0.9 & & \\ & \ddots & \\ & & 0.9 \end{bmatrix}$	$P_O = \begin{bmatrix} 0.4 & & \\ & \ddots & \\ & & 0.4 \end{bmatrix}$	$P = \begin{bmatrix} P_A & \mathbf{0} \\ \mathbf{0} & P_O \end{bmatrix}$
Standard deviation		
	$Q = \begin{bmatrix} 1 & & \\ & \ddots & \\ & & 1 \end{bmatrix}$	

6 Main Findings

In this section, I present the main results of this project by first describing the changes in the latent variables during the time period and their impact on the value added share of goods sector in the U.S. Then I will compare these results with those generated in a trade alone economy, where the MP and the technology capital are removed.

6.1 Validation of the Parameterized Model

I validate the parameterization by comparing the model generated changes in relative price of services with their data counterpart constructed as in Herrendorf, Rogerson, and Valentinyi (2013). The results are shown in Figure 5

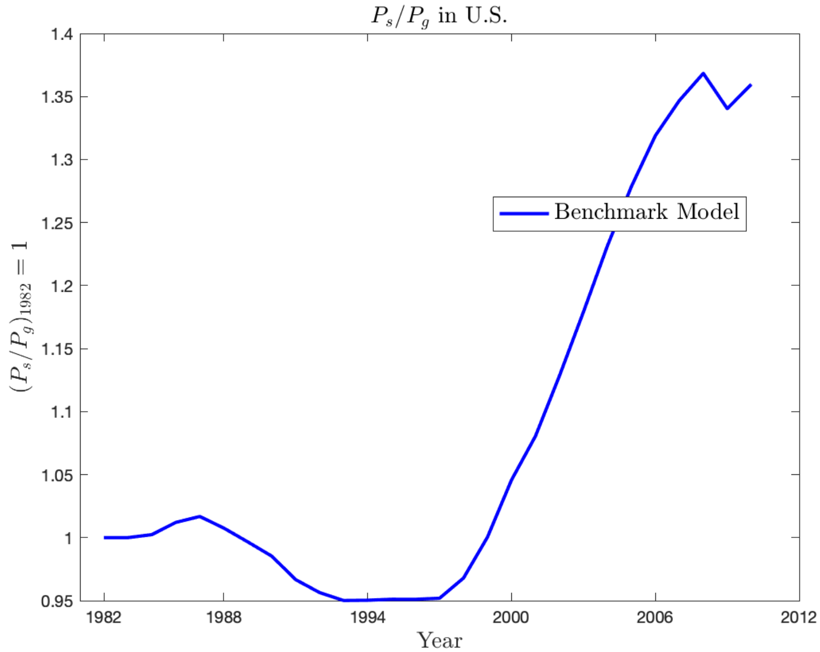

Figure 5: Change of Relative Prices between Sectors

6.2 Structural change in the U.S. from 1982 to 2012

Figure 6 and Figure 7 show each of wedges change during this period. TFP in both sectors increase in the U.S., with the TFP in service sector increases by more than faster than that of the goods sector. The degree of openness to FDI in the U.S. are similar between sectors. For the goods sector, the openness increased until 1990 and steadily decreased until 2004. The openness towards FDI in the service sector stayed constant until 2000, then decreased before plateaued starting in 2003. The U.S. trade barrier to imported goods have declined for the entire period, while that to services increased until late 1990s and declined since then.

For the rest of the world, TFP in both sectors increased from 1982 to 1994, then decreased until 2000 before increasing again in the 2000s. The rest of the world's openness towards FDI decreased slightly before 1994 and have incrased since then. The trade barriers to U.S. export of goods an d services declined until 1995, after which the trade barriers increased.

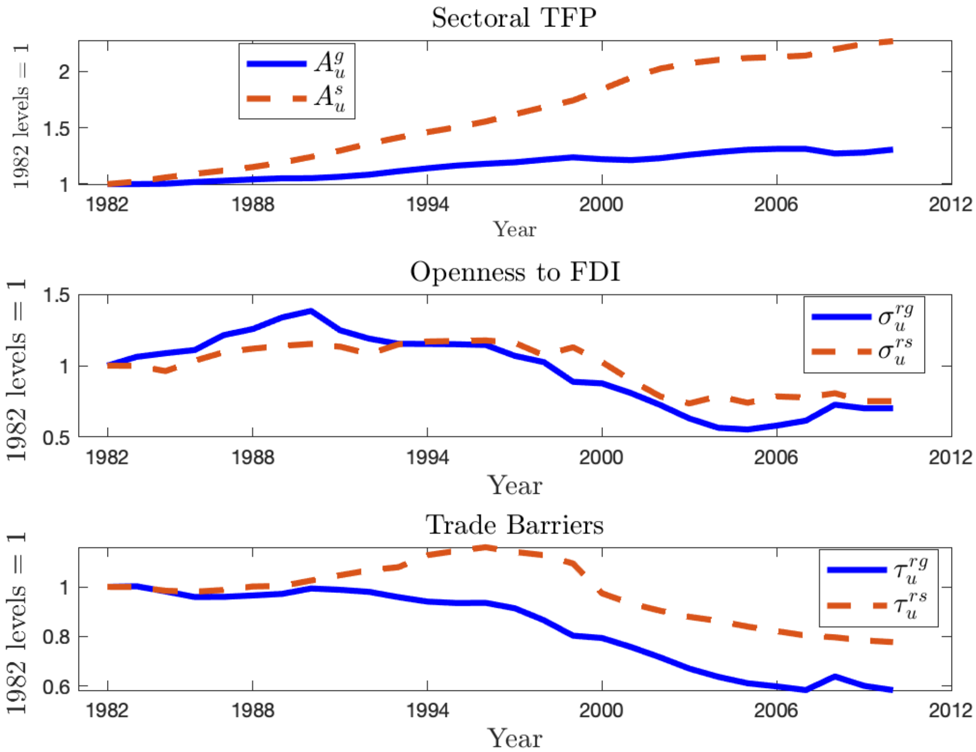

Figure 6: Wedges in the U.S.

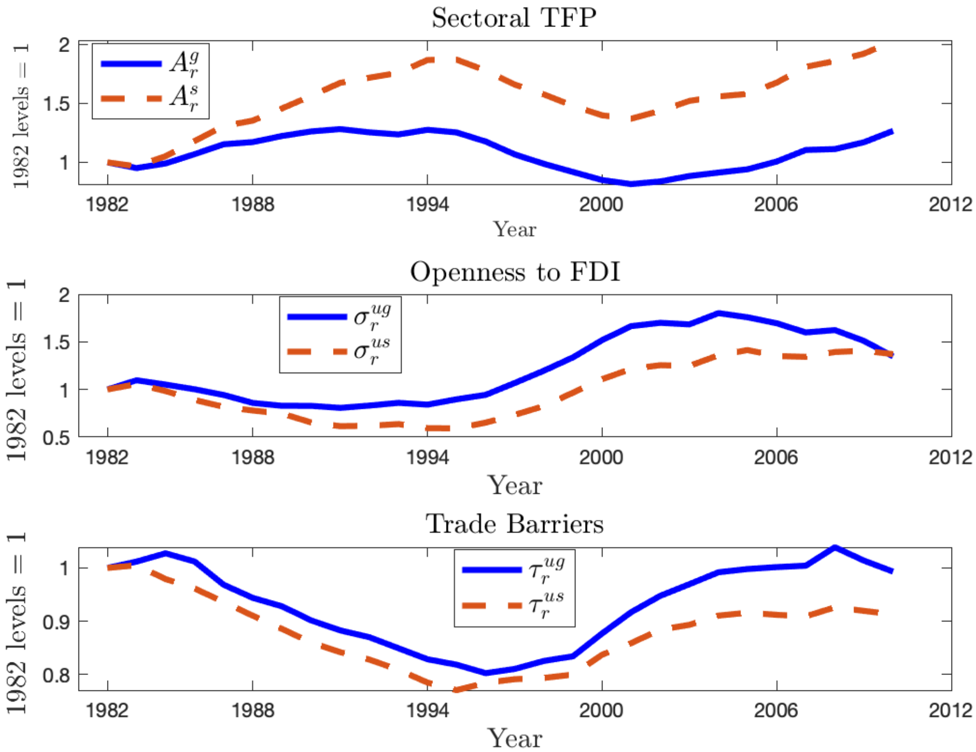

Figure 7: Wedges in the Rest of the World

To evaluate the impact of the sectoral TFP wedges, I compute the policy functions for the economy where the TFP wedges alone flunctuate while all the other wedges are set at their levels in 1982. Starting from the same initial condition, I use series of sectoral TFP wedges, the policy functions, and the law of motions of capital to simulate the counterfactual path of the U.S. economy. Suppose during 1982-2012, the only changes in the world are those of the TFPs in the U.S. and RW. Then, as is shown in Figure 8, the share of value-added of the goods sector in the U.S. would decline to 23%. The difference between this implied change and the change in reality is made up by the changes in the degree of openness of the U.S. economy in trade and direct investment.

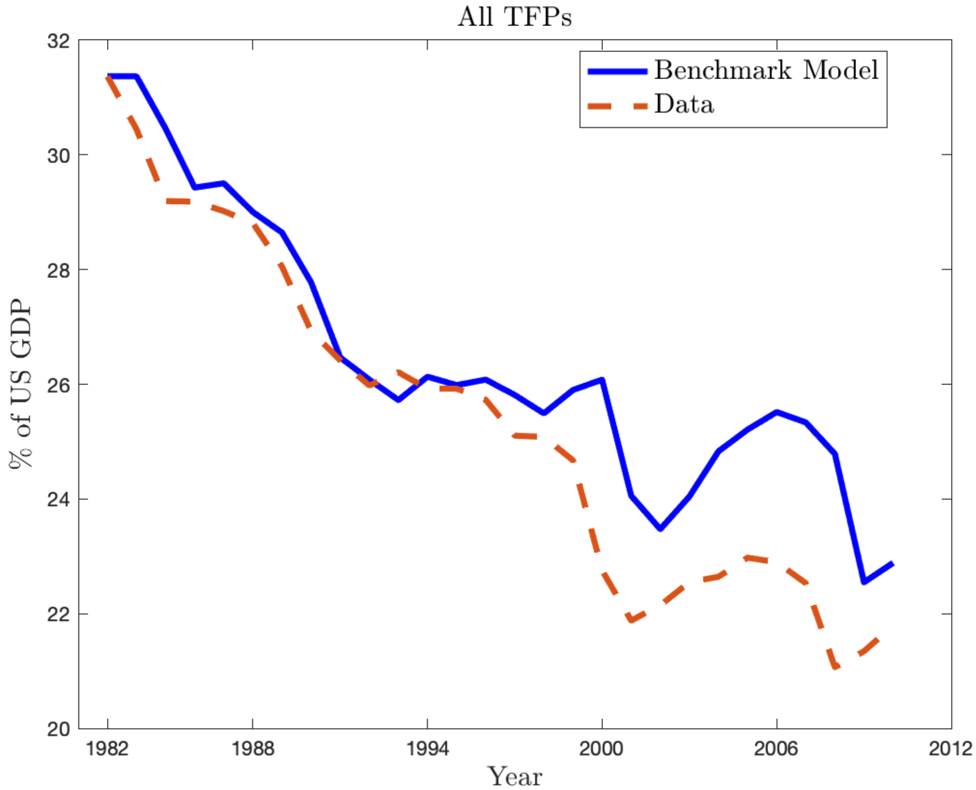

Figure 8: Counterfactual Paths of the VA Share of Goods Sector in U.S. with All TFP Shocks

To decompose the results further, consider the impact of each TFP wedge on the value-added of the goods sector in the U.S. As is shown in Figure 9, the changes of TFPs in the U.S. drive the changes in the goods sector value-added by the largest magnitudes. As A_u^g increases, the price of goods of U.S. variety manufactured in the U.S. decreases, increasing export of goods to the RW. And since in our case, goods and services are substitues, the share of goods consumption also increases in the U.S. More goods are produced in the U.S. to meet the higher demand from home and abroad.

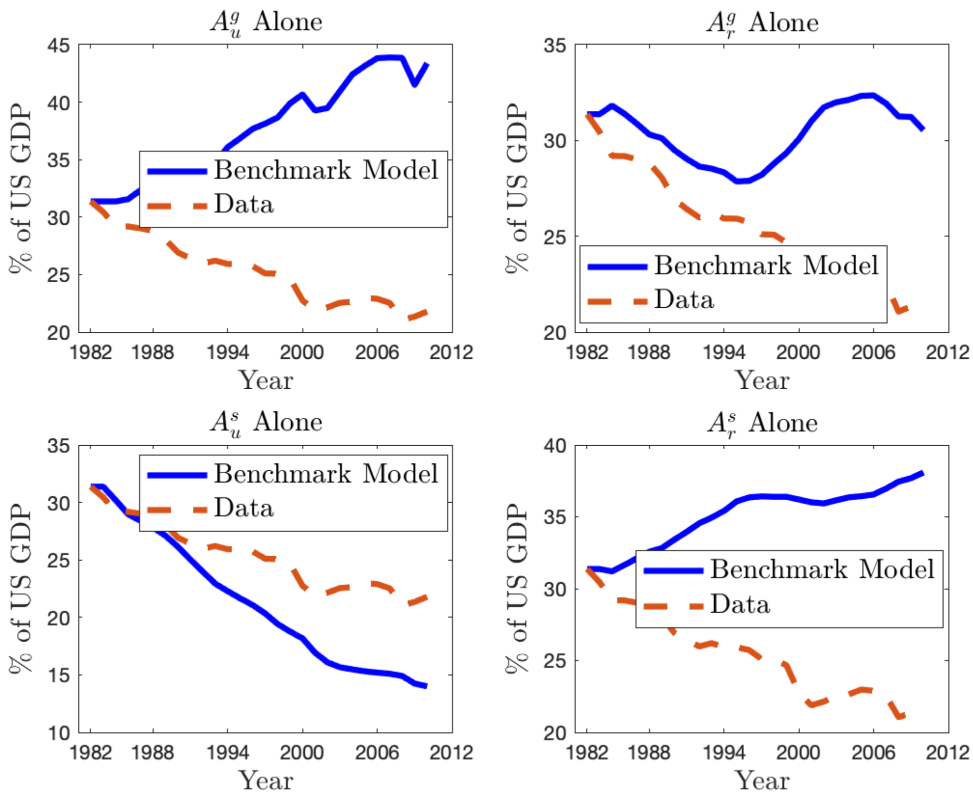

Figure 9: Counterfactual Paths of the VA Share of Goods Sector in U.S. with Each TFP Shock

6.3 Compare with the Trade Alone Economy

In this subsection, I compare the impact of the shared wedges on the share of value-added of the goods sector in the U.S. implied by the benchmark model with that in the trade alone economy, which is parameterized to match the sectoral value-added and the trade flows during the same period. The contrast of the two illustrate the additional information revealed by the MP structure and the endogenous interaction of measured productivities and the degree of openness through the technology capital of nonrivalrous usage across locations. In particular, I simulate the counterfactual paths of the measured value-added share of the goods sector in the U.S. with the individual shocks of sectoral TFPs and trade barriers as in 6.2.

As is shown in Figure 10, TFP explains less of the decline in value-added share of the goods sector in the benchmark model than it does in the trade-alone economy, because, as is shown in Figure 11, the change of TFP in RW and the TFP of the goods sector in the US increases the value-added share more than they do in the trade-alone economy. Take as an example the change of the TFP in goods sector in the U.S. When all the other wedges are held constant, the increase in A_U^g, in the benchmark model induces more investment in $M^{g,U}$ and that U.S. substitutes inward direct investment in the goods sector with imported goods for consumption of the RW variety. Through the lens of the trade-alone economy, these effects suggest that the friction of U.S. importing goods from RW has increased. In the trade-alone economy, increase of $\tau_u^{g,r}$ drives up the value-added share of goods sector in the U.S., so the impact of the increase of A_U^g alone on the share of value added of goods sector in the U.S. is dampened in the trade-alone economy compared to that in the benchmark model.

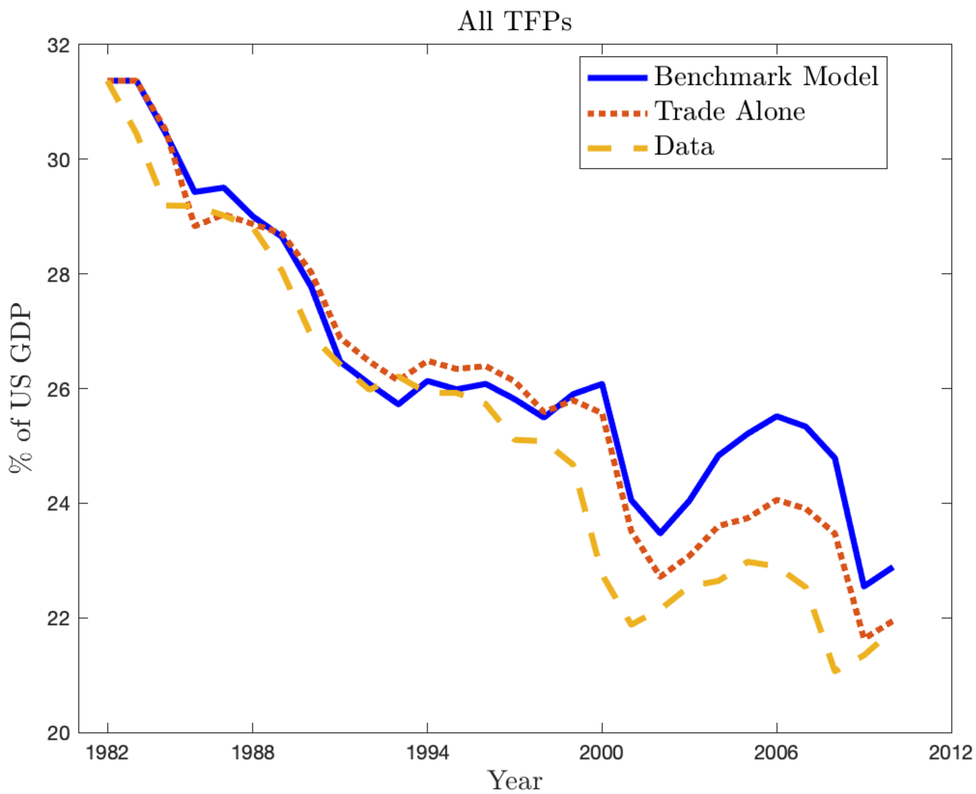

Figure 10: Counterfactual Paths of the VA Share of Goods Sector in U.S. with All Trade Shocks

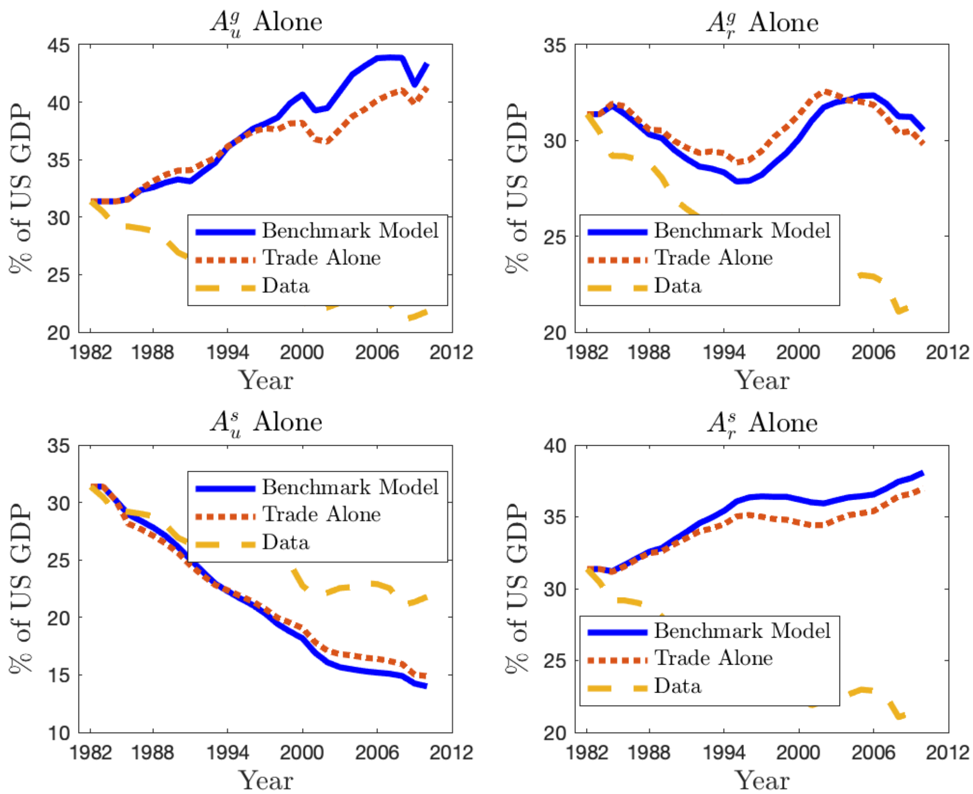

Figure 11: Counterfactual Paths of the VA Share of Goods Sector in U.S. with All Trade Shocks

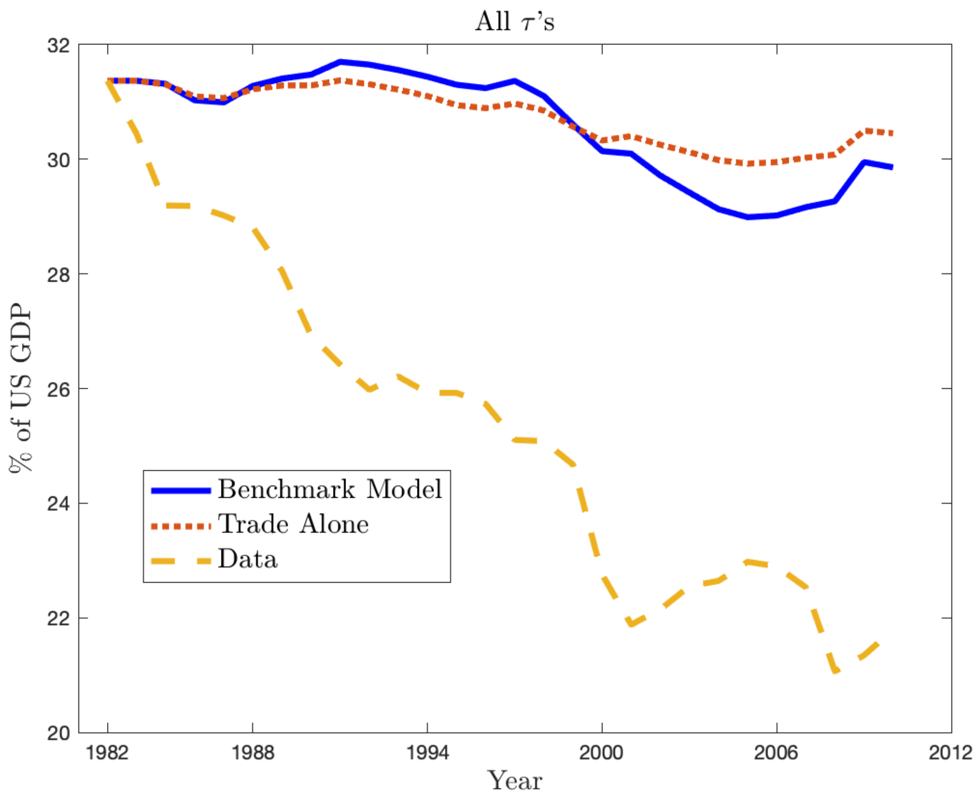

Figure 12: Counterfactual Paths of the VA Share of Goods Sector in U.S. with All Trade Shocks

7 Concluding Remarks

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