Essays on Structural Change

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Dedication

To my parents.

Abstract

This dissertation consists of three chapters. The first chapter assesses the contribution of technological progress and increased degree of openness on the reallocation of employment using a two-country-two-sector dynamic model with multinational production. I find that exogenous technological progress in the U.S. goods sector leads to a 60% growth in measured sector TFP and a one percentage point increase in the employment share of the goods sector. TFP growth in the goods sector in the rest of the world and declined trade cost on goods imported by the U.S. account for an 18 percentage point decline in the employment share in the goods sector. If the model is recalibrated to abstract from multinational production, the impact on the goods employment share is underestimated by three percentage points, accounting for 30% of the observed decline in employment share in the goods sector.

The second chapter presents the empirical details of the data used in the first chapter.

The third chapter presents a model with which I infer the producer price indices of (i) content on the internet free to the consumers created by digital platforms and (ii) own-account intangible investment by the digital platforms in their stock of data and algorithms. Both price indices lack market transaction counterparts and are important inputs to estimating the elasticity of substitution between goods and services in investment expenditure.

Contents

List of Tables

List of Figures

Chapter 1

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

1.1 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 employment share in the goods sector. However, in an open economy, the expenditure share and the employment share of a sector differ by the sectoral net export. The goods sector employment share in a country with a comparative advantage in services will fall along with the reduction of the trade barriers 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 goods sector employment share by incorporating multinational production as another form of

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

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 both countries. The parents and the affiliates share the same set of intangible capital that can be non-rivalrously used across all plants. The exogenous technology efficiency is country- and sector-specific. The parents invest in intangibles 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 and 2012 as two steady states and the transition with perfect foresight. The model is calibrated to data from the Bureau of Economic Analysis (BEA) and the World Bank. 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 change the value of one wedge at a time to its 2012 level while holding all the other wedges in the 1982 values. The implied change in goods sector employment is interpreted as the contribution of the wedge.

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 about the MNE activities, I do the same decomposition and compare with the baseline model the impact of changes in sectoral TFP and trade costs on the decline of goods sector employment share.

I find that the main driving forces are the growth in TFP in the goods sector in the rest of the world and the decline in the trade cost on U.S. imported goods. Together they account for an 18 percentage point decline in the employment share in the goods sector. If the model is recalibrated to abstract from multinational production, the goods sector employment share decreases by 15 percentage points. The difference of three percentage points accounts for 30% of the observed decline in employment share in the goods sector. The effect of the TFP growth on the reallocation of employment in both sectors in the U.S. is limited.

The results differ from the results in Kehoe, Ruhl, and Steinberg (2018) partly because, in my framework, part of the TFP growth in Kehoe, Ruhl, and Steinberg (2018) is attributed to an increased degree of openness. Indeed, I find that 40% of the growth in *measured* TFP results from an increased degree of openness and firms' endogenous responses in investing more intangible capital.

Related Literature This project extends the framework in McGrattan and Prescott (2010); McGrattan and Waddle (2020) to a multi-sector environment and contributes to the open-economy structural change literature (see, for instance, Uy, Yi, and Zhang (2013); Kehoe, Ruhl, and Steinberg (2018); Sposi (2019); Sposi, Yi, and Zhang (2021)), by taking into account multinational production and intangible capital. By including the information on bilateral FDIs, this paper disentangles firms' investment in intangible capital from the exogenous productivity wedges and trade frictions.

This paper is also related to work in structural change in a closed-economy framework. 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) Investigating the effects of changes in relative price and income on structural change, this project decomposes the measured TFP in a closed-economy into exogenous technology progress and change in frictions in trade and FDI.

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 1.2 lays out the model. Section 1.3 describes the calibration. Section 1.4 reports the main results. I conclude in section 1.5.

1.2 Model

Environment There are two countries, the U.S. and the rest of the world. Each country has a goods and a service sector and a number of homogeneous locations for production. The number of locations in a country is normalized to the country's population.

For each country, there is a representative MNE in each sector, producing country-specific variety. A MNE owns a set of intangible capital that can be used non-rivalrously across all locations. Each unit of intangible capital, when combined with location-specific production factor, z, produces

$$\sigma A z^{1-\phi}$$

$\sigma \geq 0$ captures the hosting country's regulation for foreign-owned affiliates, which otherwise are faced with the same environment as the domestic firms. $\sigma < 1$ captures FDI policies such as a requirement for joint ventures with domestic firms, whereas $\sigma > 1$ captures tax benefits for foreign affiliates. For a parent plant (i.e., a plant belonging to a MNE originated from the host country), $\sigma = 1$. A stands for the sectoral TFP in the hosting country, capturing an exogenous, common factor of efficiency shared by all plants in a sector in the country. $\phi \in [0,1]$ governs the diminishing returns to local production factor and captures the span of control of one unit of non-rivalrous intangible capital. z is a composite of physical capital, location-specific intangible capital that represents local marketization and labor,

$$z \equiv k_T^{\alpha_T} k_I^{\alpha_I} l^{1-\alpha_T-\alpha_I}$$

In the following description of the model, the superscripts are used to index for the countries of origin and for the sectors, and the subscripts are used to index for the hosting countries of plants or the destinations of trades flows.

Household's optimization Households in each country choose consumption and leisure according to $u\left(c,l\right) = \log\left(c\right) + \psi \log\left(1-l\right)$ and consume both goods and services,

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

The elasticity of substitution between goods and services, ζ, and the non-homothetic components, $\bar{c}^g$ and $\bar{c}^s$, govern the extent to which consumption responds to changes in relative price and in income. The sectoral composition of consumption is important in accounting for the structural change in the production side. In the time period being considered, consumption accounts for over sixty percent of aggregate output.

For each sector, the household consumes varieties from both countries,

$$c_i^o = c_i^o\left(c_i^{io}, c_i^{jo}\right)$$

A household can purchase foreign varieties in two ways, through import and through local affiliates,

$$c_i^{jo} = c_i^{jo}\left(c_i^{joT}, c_i^{joF}\right)$$

Households maximize utility by choosing consumption and leisure and trading a risk-free bond with the other country. Households labor is mobile between sectors and plants within a country.

$$\max_{C_{it},L_{it},B_{it+1}} \sum_{t=0}^{\infty} \beta^t N_{it} u\left(\frac{C_{it}}{N_{it}}, \frac{L_{it}}{N_{it}}\right)$$
$$s.t.$$
$$P_{it}C_{it} \leq W_{it}L_{it} + D_t^i + B_{i,t+1} - \left(1 + r_t^b\right) B_{it},$$

where the consumption expenditure, $P_{it}C_{it}$, is the sum of expenditure on all varieties from both sectors,

$$P_{it}C_{it} = N_{it} \sum_{o\in\{g,s\}} \left(p_{it}^{io}c_{it}^{io} + p_{it}^{jo,T}c_{it}^{jo,T} + p_{it}^{jo,F}c_{it}^{jo,F}\right)$$

In equilibrium, household's expenditure share on goods sector value-added is

$$s_{it}^g = \frac{1}{1 + \left(\frac{\theta}{1-\theta}\right)^{-\zeta}\left(\frac{P_{it}^s}{P_{it}^g}\right)^{1-\zeta}}\left(1 + \frac{P_{it}^g\bar{c}^g + P_{it}^s\bar{c}^s}{P_{it}C_{it}}\right) - \frac{P_{it}^g\bar{c}^g}{P_{it}C_{it}},$$

where P_{it}^o is the price index for sector $o \in \{g, s\}$. If $\bar{c}^g = \bar{c}^s = 0$, the preference goes back to standard CES and the sectoral composition of the optimal consumption bundle is invariant to changes in income. In more general cases, as their income grows, consumers allocate more (less) budget to services if $\bar{c}^s$ is positive (negative). The extent to which consumption expenditure share responds to change in income also depends on relative prices between sectors.

Firm's optimization A MNE in sector o, $o \in \{\mathrm{g, s}\}$, originated from country i, $i \in \{\mathrm{u, r}\}$, that owns M^{io} units of intangible capital optimally sets up a plant in each location and allocates the location-specific factors in both countries,

$$\max_{z_i^{io}, z_j^{io}} N_i A_i^o M^{io} (z_i^{io})^{1-\phi} + N_j A_j^o \sigma_j^{io} M^{io} (z_j^{io})^{1-\phi}$$
$$s.t.\ N_j M^{io} z_j^{io} \le Z_j^{io}, j \in \{\mathrm{u, r}\}$$

where Z_j^{io} is the total plant-specific factors hired by io in country j. The MNE's total output in country j is

$$\underbrace{A_j^o N_j^\phi \left[\left(\sigma_j^{io}\right)^{\frac{1}{\phi}} M^{io} \right]^\phi}_{\text{measured TFP of sector } o \text{ in country } i} \qquad (Z_j^{io})^{1-\phi}$$

FDI policies affect the incentive to invest in intangible capital by altering the returns to the intangible capital in the foreign country. The output is perfectly mobile within a country and can be shipped from the country of origin to its affiliates abroad subject to a country- and sector-specific iceberg cost, τ_i^{jo}, which mainly captures tariff and non-tariff trade frictions.

Given the sectoral TFP and the population in a country, the multinational's total output is in constant return to scale in the effective non-rivalrous intangible and plant-specific factors. That the number of locations is proportional to the population in a country gives rise to a scale effect. Everything else being equal, a country that experiences faster population growth also witnesses faster growth in per capita output through the strengthened incentive in investing in the non-rivalrous intangible capital provided by the increasing number of locations where it can be applied.

A MNE maximizes the present value of its global dividends,

$$\max_{\left\{y_{jt}^{io}, l_{jt}^{io}, x_{T,jt}^{io}, x_{I,jt}^{io}\right\}_{j\in\{u,r\}}, X_{M,t}^{io}} \sum_{t=0}^{\infty} q_{it} \sum_{j=u,r} D_{jt}^{io}$$
$$s.t.\ D_{jt}^{io} = N_{jt} \left[p_{jt}^{io} \left(y_{jt}^{io} - x_{T,jt}^{io} - x_{I,jt}^{io}\right) - W_{jt} l_{jt}^{io}\right] - 1_{\{i=j\}} p_{jt}^{io} X_{M,t}^{io}$$
$$k_{T,i,t+1}^{io} = (1-\delta_T) k_{T,it}^{io} + x_{T,it}^{io} - \varphi\left(k_{T,i,t+1}^{io}, k_{T,i,t}^{io}\right)$$
$$k_{I,i,t+1}^{io} = (1-\delta_I) k_{I,it}^{io} + x_{I,it}^{io} - \varphi\left(k_{I,i,t+1}^{io}, k_{I,i,t}^{io}\right)$$
$$M_{t+1}^{io} = (1-\delta_M) M_t^{io} + X_{M,t}^{io} - \varphi\left(M_{t+1}^{io}, M_t^{io}\right),$$

where q_{it} is the Arrow-Debrew price the firm inherits from the households in its country of origin, and $\varphi\left(K_{t+1}^{io}, K_t^{io}\right)$, $K = K_{T,j}^{io}, K_{I,j}^{io}$, or M^{io}, is the adjustment cost of capital.

The competition among firms in the factor markets is intact, although it is assumed that the multinationals are not allowed to trade the locations where they can set up plants. At each location, within a sector the relative size of the plants is

$$\frac{l_{it}^{jo}}{l_{it}^{io}} = \left(\frac{p_{it}^{jo}}{p_{it}^{io}}\right)^{\frac{1-(1-\phi)(\alpha_T+\alpha_I)}{\phi}} \frac{\left(\sigma_{it}^{jo}\right)^{\frac{1}{\phi}} M_t^{jo}}{M_t^{io}}$$

When $c^{io,F}$ and $c^{io,T}$ are nearly perfect substitutes,

$$\frac{l_{it}^{jo}}{l_{it}^{io}} \simeq \left(\frac{\tau_{it}^{jo} p_{jt}^{jo}}{p_{it}^{io}}\right)^{\frac{1-(1-\phi)(\alpha_T+\alpha_I)}{\phi}} \frac{\left(\sigma_{it}^{jo}\right)^{\frac{1}{\phi}} M_t^{jo}}{M_t^{io}}$$

Within a sector, the MNE that has higher effective stock of intangible capital employs more workers through a higher marginal product of labor. Employment in a foreign affiliate decreases when the cost of importing a close substitute decreases.

A multinational chooses the relative size of its parent and affiliates according to the TFP.

$$\frac{l_{jt}^{io}}{l_{it}^{io}} = \left(\frac{w_{jt}/p_{jt}^{io}}{w_{it}/p_{it}^{io}}\right)^{-\frac{1-(1-\phi)(\alpha_T+\alpha_I)}{\phi}} \left(\frac{\sigma_{jt}^{io} A_{jt}^{o}}{A_{it}^{o}}\right)^{\frac{1}{\phi}}$$

When $c^{io,F}$ and $c^{io,T}$ are nearly perfect substitutes,

$$\frac{l_{jt}^{io}}{l_{it}^{io}} \simeq \left(\frac{w_{jt}}{w_{it}} \frac{1}{\tau_{jt}^{io}}\right)^{-\frac{1-(1-\phi)(\alpha_T+\alpha_I)}{\phi}} \left(\frac{\sigma_{jt}^{io} A_{jt}^{o}}{A_{it}^{o}}\right)^{\frac{1}{\phi}}$$

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.

$$\begin{aligned} Y_{it}^{io} &= C_{it}^{io} + \tau_{jt}^{io} C_{jt}^{io,T} + X_{T,it}^{io} + X_{I,it}^{io} + X_{M,t}^{io} \\ Y_{jt}^{io} &= C_{jt}^{io,F} + X_{T,jt}^{io} + X_{I,jt}^{io} \end{aligned}$$

In equilibrium, the price index for each sector is

$$P_{it}^{o} = \left[\mu^{\rho}\left(p_{it}^{io}\right)^{1-\rho} + (1-\mu)^{\rho}\left(p_{it}^{jo}\right)^{1-\rho}\right]^{\frac{1}{1-\rho}},$$

where μ is households' bias towards the home variety, and

$$p_{it}^{jo} = \left[\left(p_{it}^{jo,T}\right)^{1-\varrho} + \left(p_{it}^{jo}\right)^{1-\varrho}\right]^{\frac{1}{1-\varrho}}$$
$$p_{it}^{jo,T} = \tau_{it}^{jo} p_{jt}^{jo}$$

In equilibrium, the bonds market and the labor market in each country clear,

$$\sum_j B_{jt} = 0$$
$$\sum_j \sum_o L_{it}^{jo} = L_{it}, i \in \{g, s\}$$

In this project, the country- and sector-specific TFP (A_{it}^{o}) and the openness to trade (τ_{it}^{jo}) and FDI (σ_{it}^{jo}) are taken as exogenous wedges. Households have perfect foresight for any transition caused by the variations of these wedges. With the bond traded between the two countries, in equilibrium, the rates of returns to all assets are equalized, and the composition of households' portfolios is indefinite.[2] The plants are indexed by their countries of origin to specify the boundaries that a certain set of intangible capital can be applied in a country. [3] That is, I assume a firm's intangible capital can be used in another country only within its affiliates. The extent to which a measured TFP growth reflects foreign MNE's investment in intangible capital can thus be inferred from the scale of operations of the affiliates in the country.

A trade-only environment By restricting $\phi = 0$ and $\sigma = 0$, the baseline model collapses into an environment with only international trade and no multinational production.

Mapping to the BEA accounts

After the revision in 2013, BEA recorded expenditures for R&D and for entertainment, literary, and artistic originals as fixed investment. To be consistent with the measurement

[2]It is assumed that households from a MNE's country of origin holds all the firm's shares.
[3]It is assumed that the MNEs do not trade among them their intangible capital.

in data, I included the intangible capital into measured GDP.

$$GDP = \sum_{o\in\{g,s\}} \left[p_{it}^{io} C_{it}^{io} + \sum_{j\in\{g,s\}} p_{it}^{jo} \left(X_{T,it}^{jo} + X_{I,it}^{jo} \right) + p_{it}^{io} X_{M,t}^{o} \right] + NX_{it}$$

For each sector o, the value-added is the sum of value-added across all plants within the sector, regardless of the plant's country of origin,

$$VA_{it}^{o} = N_{it} \left(p_{it}^{io} y_{it}^{io} + p_{it}^{jo,F} y_{it}^{jo} \right)$$

The sectoral import is

$$IMP_{it}^{o} = p_{it}^{io} \left(1 + \tau_{it}^{jo} \right) C_{it}^{jo,T}$$

The inbound FDI in sector o,

$$FDI_{it}^{o} = N_{it} p_{it}^{jo,F} \left(x_{T,it}^{jo} + x_{I,it}^{jo} \right)$$

Country i's net export is the sum of net export from both sectors,

$$NX_{it} = \sum_{o\in\{g,s\}} \left\{ IMP_{jt}^{o} - IMP_{it}^{o} \right\}$$

1.3 Calibration

In this section, I map the model to data. It is worth noting that the production side is modelled by the technology of producing a sector's value-added (rather than a sector's gross output). This requires that, in order to be consistent with the production side, (i) the consumption of goods and services are interpreted as the components of value-added from goods and service sectors contained in any commodity and services purchased by consumers , and (ii) the relevant sectoral price is the producer's price.

I calibrate the model by treating 1982 and 2012 as two steady states. Preferences and technology are kept constant overtime. The country- and sector-specific TFPs, the trade costs, and the openness to FDI are calibrated year by year to account for the the changes in GDP per capita, value added shares, trade flows, and FDI flows in the U.S. and the rest of the world over the three decades.

1.3.1 Data

The goods-producing sector defined by BEA consists of five 2-digit sectors classified under North American Industry Classification System (NAICS): *Agriculture, Forestry, Fishing and Hunting (11), Mining, Quarrying, and Oil and Gas Extraction (21), Utilities (22), Construction (23), and Manufacturing (31-33).* The service sector is constituted of the remaining fifteen sectors. [4]

I use sectoral value-added shares in place of employment shares for the U.S. and the rest of the world. In 1997, BEA reclassified the industries and NAICS replaced Standard Industrial Classification (SIC) used before 1997. BEA extended the estimation for value-added of each NAICS-defined sectors to pre-1997 years. The same estimation is not available for the employment data. With symmetric technology between sectors, in the model, the share of employment and value-added of goods sectors are the same.

Flows of import and export are obtained from the Input-Output Account in BEA. The original flows record the trade of commodities. To be consistent with the modelling of the production side, the commodity flows in each sector are converted to flows of sectoral value-added using the total requirement matrix for each year. By doing so, it is implicitly assumed that the U.S. and the rest of the world having a symmetric inter-sectoral linkage, which is consistent with the assumptions of symmetric technology throughout this project. Inward and outward FDIs are obtained from International Account in BEA.

The rest of the world GDP per capita is calculated by dividing PPP adjusted GDP in constant dollar by the population in countries that account for 70% of trade volumes of the U.S. The details are presented in Chapter 2.

On the consumption expenditure side, following Herrendorf, Rogerson, and Valentinyi (2013), I remove the trade and transportation margins from the flows of private consumption expenditure in goods and services to recover consumption in producer price and convert the flows in commodity to flows of value-added using the total requirement matrix.

	U.S.		The rest of the world	
	1982	2012	1982	2012
Goods value-added share (%)	31	20	46	41
GDP per capita	100	175	23	54

Table 1.1: Value-added share and GDP per capita

[4] Wholesale Trade (42), Retail Trade (44-45), Transportation and Warehousing(48-49), Information (51), Finance and Insurance (52), Real Estate and Rental and Leasing (53), Professional, Scientific, and Technical Services (54), Management of Companies and Enterprises (55), Administrative and Support and Waste Management and Remediation Services (56) Educational Services (61), Health Care and Social Assistance (62), Arts, Entertainment, and Recreation (71), Accommodation and Food Services (72), Other Services (except Public Administration (81), and Public Administration (92).

Sector-specific	% of Goods value-added 1982	2012	% of Services value-added 1982	2012
Import	19	47	4.7	6.4
Export	13	26	5.5	6.4
Inward FDI	0.93	3.4	0.40	0.83
Outward FDI	0.39	3.2	0.05	1.8

Table 1.2: Trade and FDI flows in percentage of U.S. sectoral value-added

With U.S. GDP per capita in 1982 normalized to 100, consumers income, over the three decades, increased in both countries, suggesting an income effect in increased demand for service. The rest of the world is growing faster than the U.S. The trend that the rest of the world getting more efficient potentially led U.S. MNEs to choose FDI over trade to access the foreign market.

1.3.2 Time-invariant parameters

Exploiting the variations in relative prices and relative expenditure shares, I estimate the share, the non-homothetic component, and the elasticity of substitution in the preference by minimizing the distance between the consumption expenditure share of goods in the data with the share implied by the preference structure, given the series of relative prices and total consumption expenditure.

The discount factor is set at 0.98 for a real interest rate at 4%. Following McGrattan and Prescott (2010) , the capital shares are set to match the annual expenditure on R&D and national advertising along with the market value of U.S. business. I take from Simonovska and Waugh (2014); McGrattan and Waddle (2020) the elasticities of substitution in the Armington demand system.

Pre-determined parameters		Moments	Value
trade shares, elasticities	μ, ρ, ϱ		0.5, 4, 15
non-rivalrous intangible capital	ϕ, δ_M	U.S. annual expenditure in R&D and advertising	0.07,0.06
plant-specific intangible capital	α_I,δ_I	the market value of U.S. busines	0.3,0
plant-specific tangible capital	$(1-\phi)\alpha_T, \delta_T,$	K/Y,X/K	0.37,0.06
asset position	B_{1982}, B_{2012}	U.S. net export & net factor income	0.7, -3.6
population	$N_{u,1982}, N_{r,1982}$	ratio of population	1, 7.1
	$N_{u,2012}, N_{r,2012}$		1.4, 9.4

Table 1.3: Pre-determined parameters, technology

Calibrated parameters		Moments	value
disutility of labor	ψ	1/3 hours in labor	1.4
non-homotheticity	$\bar{c}^s$	$\frac{p^s_{u,1982}\bar{c}^s_{u,1982}}{P_{u,1982}C_{u,1982}} = 0.12$	0.45

Table 1.4: Pre-determined parameters, preference

1.3.3 Time-varying wedges

I back out the values of time-varying latent variables by matching moments in the model to moments in the data for each year. In particular, I use (i) value added share, (ii) trade flows, and (iii) FDI flows, to inform, for each country and sector, the (i) TFPs (ii) iceberg cost and (iii) degree of openness to FDI.

The differences in investment flows undertaken by the domestics firms (embedded in the sectoral value added) and by the foreign-owned affiliates are informative about the degree of openness to FDI, which is modelled as an efficiency parameter associated to foreign-owned affiliates which otherwise are faced with the same environment with the domestically owned firms.

The variations in the trade flows reflect the changes of the relative prices of the home and foreign varieties, which are affected and hence reflect both the change of iceberg costs and the changes of country- and sector-specific TFPs. While both an increase in the rest of the world TFP and a decrease in the iceberg cost on U.S. goods imports lead to a higher import flow in U.S. goods sector, a decline in the iceberg cost channels more employment into the goods sector and an increase in TFP diverts the employment away in the rest of the world. So by the variations in the value-added share within each country, one can distinguish the changes in TFP and changes in trade cost.

TFP	1982	2012	Trade cost	1982	2012	Openness to FDI	1982	2012
A^g_u	4.9	6.4	τ^{rg}_u	2.0	1.0	σ^{rg}_u	0.6	0.8
A^s_u	3.2	4.1	τ^{rs}_u	2.7	2.7	σ^{rs}_u	0.4	0.5
A^g_r	2.5	3.4	τ^{ug}_r	1.6	1.6	σ^{ug}_r	0.5	0.6
A^s_r	1.5	2.3	τ^{us}_r	2.0	1.5	σ^{us}_r	0.3	0.6

Table 1.5: Time-varying wedges in the baseline model

I calibrate sectoral TFP and trade cost in the restricted model using (i) sectoral value-added and (ii) trade flows.

	1982	2012		1982	2012
A_u^g	7.9	12.5	τ_u^{rg}	1.8	1.0
A_u^s	4.6	6.2	τ_u^{rs}	2.2	2.9
A_r^g	3.5	5.2	τ_r^{ug}	2	2.1
A_r^s	1.7	3.1	τ_r^{us}	2.9	1.9

Table 1.6: Time-varying wedges in the trade-only environment

In both versions of the model, TFP grew in both sectors in the U.S. and the rest of the world, which is consistent with growth in GDP per capita and despite the decline in goods sector employment in both countries. There is large decline in trade cost on U.S. imports of goods and the rest of the world's imports of service, while the other two iceberg costs remain unchanged or slightly increased. Both the U.S. and the rest of the world become more open to FDI.

1.4 Main Results

In this section, using the calibrated parameters, I decompose the decline of employment share in U.S. goods sector from 1982 to 2012 by its driving forces. I hold all wedges in 1982 level and switch one wedge at a time to its value in 2012. I then compare the decomposition in the baseline model and in the restricted model and decompose the TFP change in the restricted model to TFP changes, the change of intangible capital and the reallocation between domestic firm and hosted foreign affiliates in the baseline model. Finally, I discuss the assumptions and pre-determined parameters that can affect the identification.

1.4.1 Decomposing of the decline in employment share

Table 1.7 shows the counterfactual employment share in the U.S. had the only change in the world economy been the wedge in the first column. The observed decline in the data is recovered if all wedges are switched to their values in 2012. This analysis reveals that the main driving forces are the TFP growth in the rest of the world goods sector and the declined iceberg cost in U.S. import of goods from the rest of the world.

Turn on		Goods Sector Value-added Share (%), 2012	
		Baseline	Trade only
TFP	US Goods	32	29
	US Services	30	32
	RoW Goods	13	16
	RoW Services	57	54
Iceberg costs	RoW to US, Goods	20	23
	RoW to US, Service	31	29
	US to RoW, Goods	31	31
	US to RoW, Service	28	27
Openness to FDI	RoW in US, Goods	33	
	RoW in US, Service	30	
	US in RoW, Goods	29	
	US in RoW, Service	33	

Table 1.7: Value-added share, US goods sector

TFP growth in the goods sector in the rest of the world Anticipating cheaper prices of imported goods following the goods sector's TFP growth in the rest of the world, U.S. consumers' permanent income rise. Since the income elasticity of service is above unity, U.S. consumers demand more services. As the price of service increases, U.S. employment is reallocated to the service sector even before the TFP growth in the rest of the world is fully realized.

As the prices fall, consumers in both countries substitute towards goods produced in the rest of the world. Although consumers in the rest of the world demand more from the goods-producing U.S. affiliates, since the elasticity of substitution between country-specific varieties is above one, overall, the demand decrease for goods produced using the U.S. blueprints. Moreover, the price of the U.S. goods-producing affiliates' output declines by more compared to the price of its parent's output in the U.S., in the latter of which is the investment in technology capital denominated. The returns to the technology capital in U.S. goods sector falls, and the U.S. goods-producing MNE de-invests in their technology capital. U.S. consumers lend the extra savings to the rest of the world to take advantage of the higher returns to the investment in their goods sector. U.S. affiliates invest more in location-specific physical capital to meet the increased demand for their output. In the U.S, workers leave the goods-producing sector not only because of lower demand for consumption but also the declined demand for investment. Moreover, as capital is formed in firms' own product, the cost of capital declines in U.S. goods sector, and the plants substitute by employing more capital per worker.

As the price of goods decline, consumers in both countries demand more services as complements. The technology capital of the U.S. service sector has more labor to work with in both countries. The price of U.S. service-producing affiliates increases by more compared to the price of its parent's output. The return to the technology capital of the U.S. service producing MNE increases, and the U.S. invests more in its service capital.

In a model that abstracts from multinational production, the investment in technology capital made by the parents is interpreted as a TFP changes in the other country hosting the affiliates. In particular, the TFP growth in the rest of the world's goods sector is interpreted as the TFP growth in the U.S. goods sector, the TFP growth in the rest of the world's goods sector but by a smaller magnitude, together with TFP growth in service sectors in both countries. Moreover, abstracting from the substitution between exporting and FDI requires a larger increase in the rest of the world TFP to rationalize the decline in U.S. export of goods, and hence understate the contribution of the rest of the world's TFP growth on U.S. goods sector employment.

Decline in iceberg cost on U.S. imports of goods In the same way as following a growth of TFP in the rest of the world's goods sector, the U.S. consumers' permanent income rises, lend more to the rest of the world, and substitute towards imported goods. Consumers in the rest of the world, however, import more goods from the U.S., since the prices of the rest of the world output have to increase to compete for workers to satisfy the other demand beside exporting goods. However, the rest of the world is much larger than the U.S. in size, the rest of the world's import of goods from the U.S. is limited by the increase in the price of U.S. goods, and crowds out the U.S.'s consumers demand for the U.S. variety. Overall, the demand for U.S. goods decreases, and the goods-producing MNE in the U.S. de-invest in the technology capital.

Although the U.S. service-producing affiliate is faced with higher cost of location-specific factors, this is more than offset by the increased demand for U.S.-produced services from both countries. Employment is reallocated to the service sector in the U.S., and the U.S. service MNE invests more in its technology capital.

A model that abstracts from multinational production interprets the improved efficiency as a lagged growth in the TFP of the U.S. goods sector and the rest of the world service sector.

1.4.2 Decomposing Measured TFP

Through the lense of the baseline economy, the measured TFP as a Solow residual captures the exogenous sectoral technology, market size, and openness to trade and FDI, and the endogenous responses of the MNEs' in both countries. The change in the measured TFP can be decomposed into changes of the exogenous factors.

measured TFP of sector $o|_t$

$$\equiv \frac{\left(p_{it}^{io} Y_{it}^{io} + p_{it}^{jo} Y_{it}^{jo}\right)/P_{it}^{o}}{\left[\left(p_{it}^{io}\left(K_{T,it}^{io} + K_{I,it}^{io} + M_{it}^{io}\right) + p_{it}^{jo}\left(K_{T,it}^{jo} + K_{I,it}^{jo}\right)\right)/P_{it}^{o}\right]^{\alpha}\left(L_{it}^{io} + L_{it}^{jo}\right)^{1-\alpha}}$$

Turn on	% change in measured TFP in U.S. , 2012	
	Goods Sector	Service Sector
TFP	41	37
Openness to Trade and FDI	9	3
Population	-2	-2
all lines	52	40

Table 1.8: Changes in measured TFP

1.4.3 Discussion

In the decomposition of the goods sector employment, U.S. asset position in 2012 is fixed to its 1982 level, which leads to the U.S. counterfactually lending to the rest of the world in 2012, which may cause understatement of the impact of the changes in U.S. TFP and the rest of the world's openness to U.S. export and outbound FDI. [5] Shortcomings as such can be overcome by calibrating the entire transition path without imposing steady states in the initial and the ending period. This is currently work in progress.

1.5 Conclusions

Using a two-country, two-sector model with multinational production, I assess the contribution of TFP growth, reduced trade barrier, and increased degree of openness to the decline of goods sector employment in the U.S. from 1982 to 2012.

I find that the exogenous technological progress, accounting for 60% of the measured TFP growth in U.S. goods and service sectors, leads to a one percentage point decrease in goods sector employment; the remaining of growth in measured TFP reflects increased degree of openness to trade and FDI and firm's investment in intangible capital. TFP growth in the goods sector in the rest of the world and declined trade cost on goods imported by the U.S. account for more than a hundred percent of the reallocation of employment. If the

[5] Following these changes, U.S. multinationals would invest more had the U.S. need not maintain its asset position in 1982.

model is recalibrated to abstract from multinational production, the impact is understated by three percentage points of total employment which is 30% of the decline.

Chapter 2

Empirical Details of Processing Data from BEA Accounts

In this chapter, I present the details of the empirical procedure used to transform the raw data from BEA into moments used in the first chapter.

2.1 Sector value-added

The series of sector value-added for the United States are obtained from the use tables at the summary level. I follow the BEA definition and have the goods-producing sector including, in terms of two-digit industry, agriculture, mining, manufacturing, and construction.

In 1997, BEA switched from SIC to NAICS, and the industry codes were reassigned to establishments according to their production activities instead of the main business of their headquarters. From SIC to NAICS, new 2-digit industries were created and industries bearing the same name map to different sets of production activities. To resolve the inconsistency in definition, I use the use tables at the summary level where industries and commodities are classified by the 4-digit BEA industry code. The concordances between the BEA industry code and NAICS code provided a consistent measure of NAICS 2-digit industries and commodities before and after the reclassification.

The series of sector value-added from the rest of the world is obtained from the World Bank, with the industry sector used as a proxy for the goods sector in countries other than the U.S. The industry sector includes mining, manufacturing, construction, electricity, water, and gas, as 2-digit industries classified according to ISIC Rev.4.

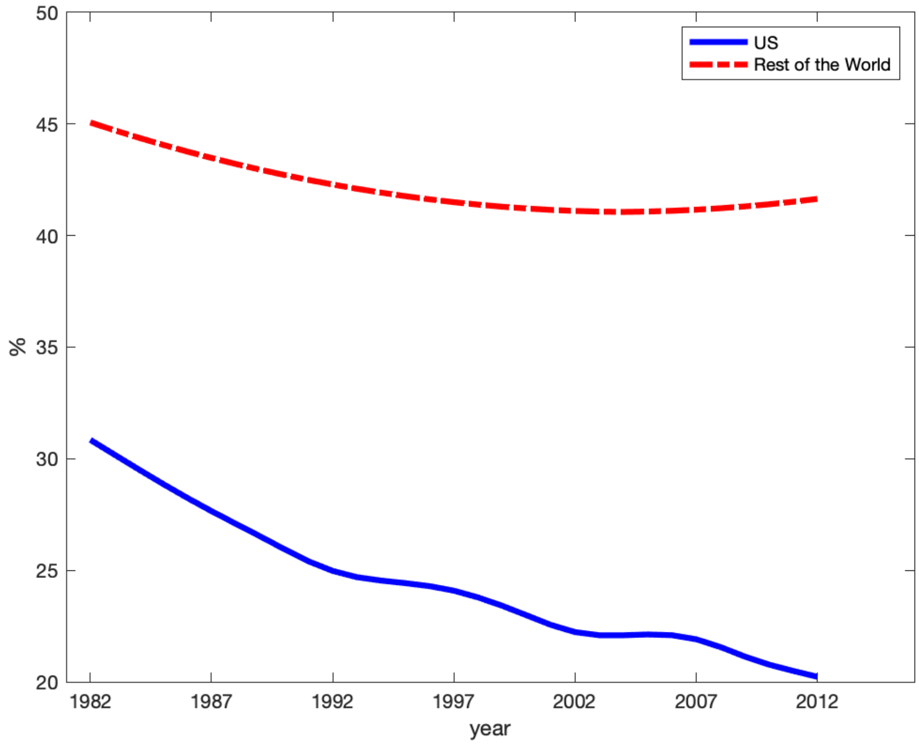

Figure 2.1: Sector Value-added of Goods Sector as Share of GDP

2.2 Value-added in sector trade flows

The value-added from the goods and the service sectors embedded in the trade flows of commodities and services are calculated from the use and the make tables in the 4-digit industry code level (i.e., the summary level) in the BEA industry account.First, the commodities (industries) in the rows (columns) are first aggregated into 2-digit NAICS commodities (industries).

For the use tables, the entries are recorded in the producer's value. For the export, the values of transporting the export to the port before exiting the U.S. is excluded and reassigned to the export of transportation and warehousing commodities. So the values in the column of "Export of goods and services" are consistent with those for domestic use.

For each imported commodity (except for transportation and wholesale trade), the cell is denominated in domestic port value, which is the sum of customs duty, freight, and foreign port value. The offsetting items for the usage of domestic freight and the customs duty are included in the commodities of transportation and wholesale trade. Under the assumption of homogeneity within each commodity category, the domestic port value is equivalent to the basic price for domestically supplied commodities.

The value-added from each sector embedded in the commodities for export are extracted using the industry-by-commodities total requirement tables constructed as follows. Let

- U: intermediate inputs of use table
- V: make table
- g: vector of gross output of industries
- q: vector of gross output of commodities
- r: vector of ratios of value-added to gross output of each industry
- ex: vector commodities for export

Define

$$D = V\hat{q}^{-1}$$
$$E = U\hat{g}^{-1}$$

where a vector with $\widehat{}$ denotes a diagonal matrix with the vector being the main diagonal. The industry-by-commodities total requirement table,

$$TR \equiv D(I - ED)^{-1}$$

The value-added from each industry in the commodities for export is obtained by

$$TR \cdot ex \cdot \hat{r}^{-1}$$

The value-added from each industry in the import commodities is recovered by the same method. Admittedly, foreign production, in general, has a different inter-sectoral structure than that in the U.S. However, the world input-output tables are unavailable before 1994. The interpretation of value-added resulting from decomposing the import by the U.S. total requirement table is the additional value-added produced by each industry if the imported commodities were produced domestically.

In the following, I plot the series of imports and exports as shares of the industry's value-added. HP filter is applied to capture the trends.

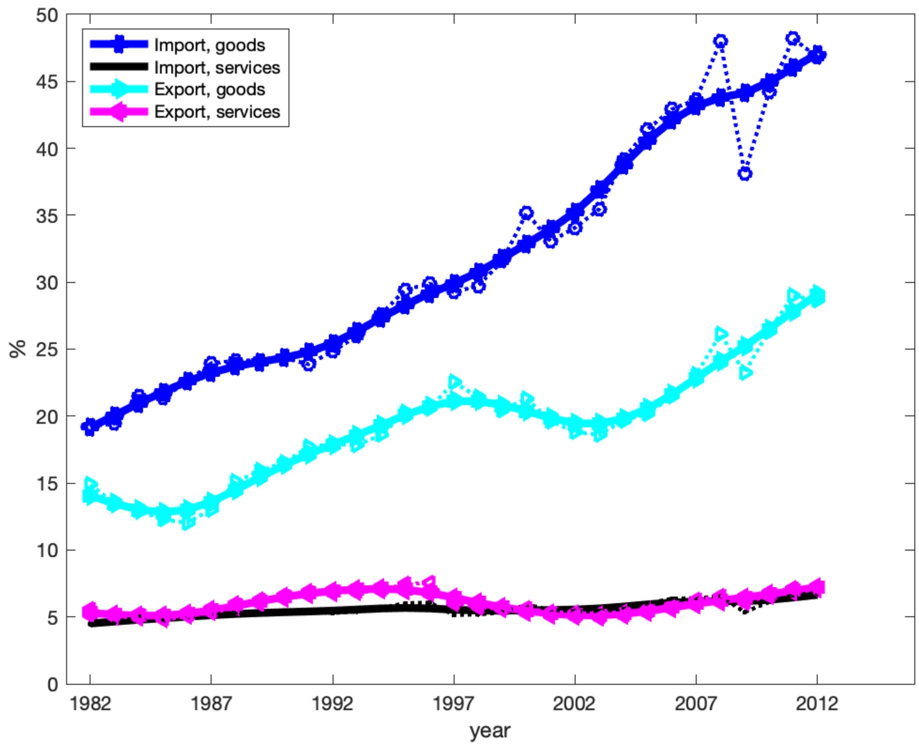

Figure 2.2: Trade Flows as Fractions of Sector Value-added

2.3 FDI

The flows and positions of direct investment are obtained from ITA and IIP accounts at BEA. The direct investment for each industry is recorded on the directional basis and without current cost adjustment. The directional basis records direct investment as inward and outward. The outward direct investment is the sum of the parents' equity in the affiliates and the parents' claim on the affiliates net of the affiliates' claims on the parents. The inward direct investment in the sum of foreign parents' equity in the affiliates located in the U.S., and the claim of foreign parents net of the claims of the U.S. affiliates. The outward directional basis captures the direct investment initiated by the same as its model counterpart.

The presentation of industry-specific direct investment positions is on historical basis, and the current cost adjustment of the equity is only available at the aggregate level. I assume that the amount needed to be adjusted is evenly distributed across industries. HP filter is applied to capture the trends.

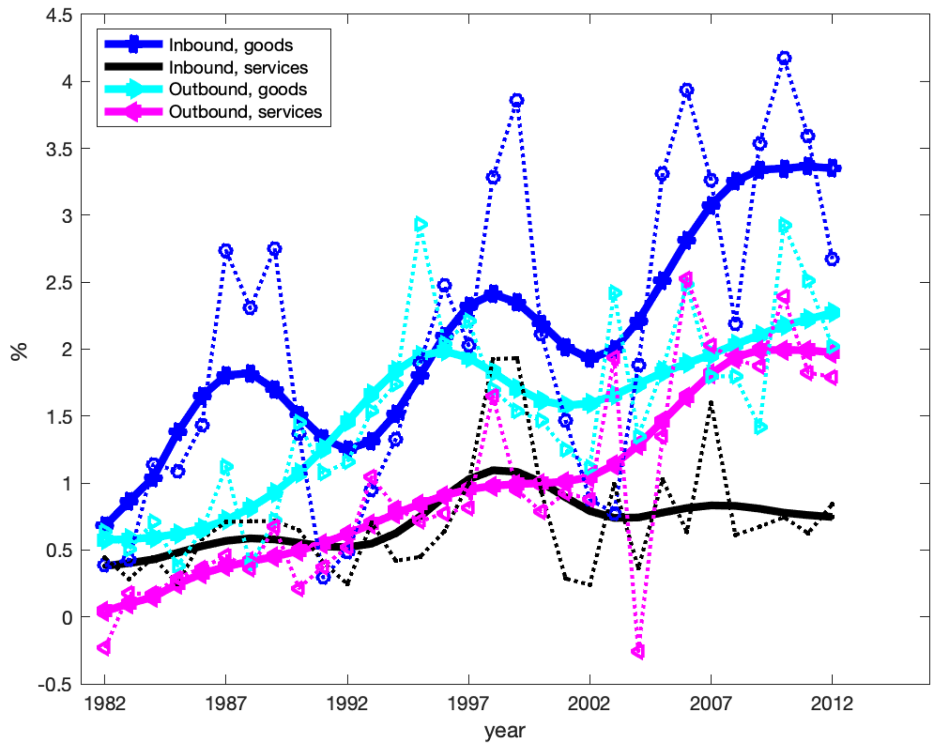

Figure 2.3: FDI Flows as Fractions of Sector Value-added

2.4 The rest of the world

Americas: Argentina, Bahamas, Bermuda, Brazil, Canada, Chile, Mexico,
Asia Pacific: Australia, China, Hong Kong, Taiwan, Japan, Korea (Republic of)
Europe: Belgium, France, Germany, Ireland, Italy, Netherlands, Norway, Spain, Switzerland, UK, United Kingdom Islands (Caribbean)

These countries account for about seventy percent of trade, and FDI flows originated from and received by the U.S. For each country, PPP-adjusted per capita GDP is obtained from the World Bank. In the graph, the GDP per capita in the United States in 1982 is normalized to one.

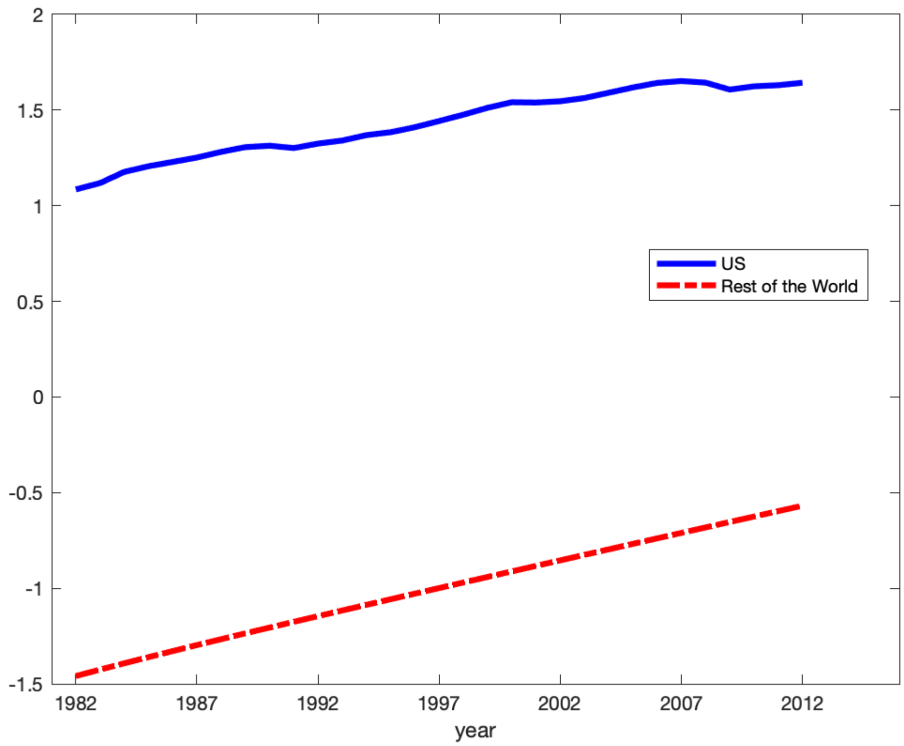

Figure 2.4: GDP per capita, PPP adjusted

Chapter 3

Inferring Producer Price Indices of Services Produced by Digital Platforms

3.1 Introduction

The rise of digital platforms in the service sector poses new challenges to the estimation of the price index of services as an essential input for the research studying structural change. In particular, the key outputs of the digital platforms are not mediated through markets with explicit prices – digital platforms create online content accessible to consumers free of charge in exchange for viewership, which the platforms use as an input investing in their stock of data and algorithms. Within a platform, intangible capital such as the stock of data and algorithms has non-rivalrous usage across divisions. Thus, the cost-based method is not directly applicable when estimating the price of intangible investment.

In this chapter, I develop a model with which I attempt to infer the producer price indices for platforms' investment in data and algorithms and the online recreational services free to the consumers.

The model environment consists of a traditional sector representing all businesses producing goods and services with explicit market prices, a nontraditional sector resembling digital platforms, and a representative household. The household spends leisure time online browsing content created by the nontraditional sector without any monetary payment. In exchange, the viewership is used by the nontraditional business as an input in production. With platform-specific know-how, the traces of the household's browsing are transformed into investment in the platform's stock of data and algorithms, which, together with tangible capital and labor, are used to create online content and to produce marketing services sold to the traditional sector.

The model is presented in the next section, and extension to an open-economy environment is discussed in section 3.

3.2 Model

In this section, I lay out the model environment and the optimization problems, and derive the equilibrium conditions which recover (i) the shadow price of the platform's investment in its stock of data and algorithms and (ii) the shadow (producer) price of the online content free of charge to the consumers.

3.2.1 Environment

Preference

A representative household divides their time between work in the labor market and leisure. Assume browsing the free content online is the only recreation of which the household takes the quality, θ, as given. The household consumes goods and services as a composite.

$$u\left(c_{gs}, c_l\right) = \log\left(c_{gs}\right) + \psi c_l$$
$$c_l = c_l\left(\theta, l\right) = \theta \log l$$
$$l + h = 1$$

Technology

Traditional sector A representative firm in the traditional sector produces the composite of goods and services using labor and its brand name as intangible capital.

$$y_{gs} = A_{gs} a_{gs}^{\alpha_a} h_{gs}^{1-\alpha_a}$$
$$a_{gs,t+1} = \left(1 - \delta_a\right) a_{gs,t} + x_{a,t}^d$$

Nontraditional sector The nontraditional sector differs from the traditional one in that its production uses viewership as an input, and its intangible capital consists of the stock of data and algorithms. A representative firm produces marketing services, the quality of online content, and investment in its stock of data and algorithms,

- advertising service for to the traditional sector,

$$x_a = \left(A_a k_a^{\alpha_1} d^{\alpha_2} h_a^{1-\alpha_1-\alpha_2}\right)^{\mu} \left(l^d\right)^{1-\mu}$$

- quality of online content free to the household,

$$\theta = \left(A_\theta k_\theta^{\alpha_1} d^{\alpha_2} h_\theta^{1-\alpha_1-\alpha_2}\right)^\mu \left(l^d\right)^{1-\mu}$$

- investment in the stock of data and algorithms,

$$x_d = \left(A_d k_d^{\alpha_1} d^{\alpha_2} h_d^{1-\alpha_1-\alpha_2}\right)^\mu \left(l^d\right)^{1-\mu}$$

The stock of data and algorithms evolves according to

$$d_{t+1} = x_{d,t} + (1-\delta_d)\, d_t \tag{1}$$

3.2.2 Optimization

Household The price of the composite of goods and services is normalized to one. The consumption expenditure is financed by the household's labor income and dividends distributed by the firms in the traditional and the nontraditional sectors. The household can access online content produced by the nontraditional sector free of charge.

$$\begin{aligned} \max \sum_t \beta^t u\left(c_{gs,t}, c_{l,t}\right) \\ c_{gs,t} =& w_t h_t + \sum_{i=tr,ntr} \left[s_t^i \left(d_t^i + v_t^i\right) - s_{t+1}^i v_t^i\right] \\ &+ \left(1 + r_t^b\right) b_t - b_{t+1} \end{aligned}$$

Holding all the other factors constant, the higher quality of online content, the household spends more time browsing,

$$l_t = \frac{\psi \theta_t c_{gs,t}}{w_t} \tag{2}$$

Traditional sector The firm purchases advertising services from the nontraditional sector as an investment in its brand name.

$$\begin{aligned} \max_{h_{gs,t}, x_{a,t}^d} \sum_{t=0}^{\infty} p_t d_t^{tr} \\ d_t^{tr} &= p_{gs,t} y_{gs,t} - w_t h_{gs,t} - p_{a,t} x_{a,t}^d \\ a_{gs,t+1} &= (1-\delta_a)\, a_{gs,t} + x_{a,t}^d \end{aligned}$$

Nontraditional sector The firm takes as given the schedule of quality of the content online and the household's browsing time implied by the household's optimal time use, and purchases the composite of goods and services from the traditional sector to invest in the tangible capital.

$$\max_{h_d,h_a,h_\theta,x_{k,\cdot}} \sum_{t=0}^{\infty} p_t d_t^{ntr}$$

$$\begin{aligned} d_t^{ntr} &= p_{a,t}x_{a,t} - w_t\left(h_{d,t}+h_{\theta,t}+h_{a,t}\right) \\ &\quad - \left(x_{ka,t}+x_{k\theta,t}+x_{kd,t}\right) \\ x_{a,t} &= \left(A_{a,t}k_{a,t}^{\alpha_1}d_t^{\alpha_2}h_{a,t}^{1-\alpha_1-\alpha_2}\right)^{\mu}\left(l_t\left(\theta\right)\right)^{1-\mu} \\ \theta_t &= \left(A_{\theta,t}k_{\theta,t}^{\alpha_1}d_t^{\alpha_2}h_{\theta,t}^{1-\alpha_1-\alpha_2}\right)^{\mu}\left(l_t\left(\theta\right)\right)^{1-\mu} \\ x_{d,t} &= \left(A_{d,t}k_{d,t}^{\alpha_1}d_t^{\alpha_2}h_{d,t}^{1-\alpha_1-\alpha_2}\right)^{\mu}\left(l_t\left(\theta\right)\right)^{1-\mu} \\ l_t\left(\theta_t\right) &= \frac{\psi\theta_t c_{gs,t}}{w_t} \\ d_{t+1} &= x_{d,t} + \left(1-\delta_d\right)d_t \\ k_{\cdot,t+1} &= x_{k\cdot,t} + \left(1-\delta_k\right)k_{\cdot,t}, \cdot \in \{d,\theta,a\} \end{aligned}$$

3.2.3 Market Clearance

Market transactions exist for three commodities: the composite of goods and services, labor, and marketing services.

$$\begin{aligned} c_{gs,t}+x_{ka,t}+x_{k\theta,t}+x_{kd,t} &= y_{gs,t} \\ h_{d,t}+h_{\theta,t}+h_{a,t}+h_{gs,t} &= h_t \\ x_{a,t} &= x_{a,t}^{d} \end{aligned}$$

3.2.4 Inferring Producer Price Indices

The hours employed to produce the marketing service is obtained from the observable sales,

$$h_{a,t} = \frac{\mu\left(1-\alpha_1-\alpha_2\right)p_{a,t}x_{a,t}}{w_t}$$

The hours employed to produce online content and investment in data can be calculated as a residual of aggregate hours net of the hours employed by the traditional sector and for the marketing services,

$$h_{d,t}+h_{\theta,t} = h - h_{gs,t} - h_{a,t}$$

In equilibrium, the ratios among factors employed for the three divisions in the nontraditional sector are equalized, which implies

$$q_{d,t}x_{d,t} + q_{\theta,t}\theta_t = \frac{h_{d,t} + h_{\theta,t}}{h_{a,t}} p_{a,t}x_{a,t} \tag{3}$$

From the first-order condition with respect to θ_t,

$$q_{\theta,t}\theta_t = \frac{1-\mu}{\mu}\left(p_{a,t}x_{a,t} + q_{d,t}x_{d,t}\right) \tag{4}$$

Combining equation (3) and (4) gives the value of investment in the stock of data as a fraction of sales of the marketing service,

$$q_{d,t}x_{d,t} = \mu\left(\frac{h_{d,t} + h_{\theta,t}}{h_{a,t}} - \frac{1-\mu}{\mu}\right) p_{a,t}x_{a,t} \tag{5}$$

Substitute (3) into the Euler's equation for the stock of data,

$$\left(1 + r^b_{t+1}\right) q_{d,t} = q_{d,t+1}\left(1 - \delta_d\right) + \mu\alpha_2 \frac{\left(1 + \frac{h_{d,t+1}+h_{\theta,t+1}}{h_{a,t+1}}\right) p_{a,t+1}x_{a,t+1}}{d_{t+1}} \tag{6}$$

The series of $q_{d,t}$ can be recovered with the initial values of the stock of data, d_0, and price of investment, $q_{d,0}$. Specifically, $x_{d,0}$ can be solved from (5), and then d_1 from (1), and $q_{d,1}$ from (6). The process proceeds recursively.

The series of $q_{\theta,t}$ can be recovered by (2), (4), and (5). In particular, first substitute (5) into (4) to write $q_{\theta,t}\theta_t$ as a fraction of sales of marketing service,

$$q_{\theta,t}\theta_t = (1-\mu)\left(\frac{h_{d,t} + h_{\theta,t}}{h_{a,t}} + 1\right) p_{a,t}x_{a,t} \tag{7}$$

Then solve for $q_{\theta,t}$ by dividing both sides of (7) by θ_t, which can be backed out from (2).

3.3 Extensions

3.3.1 Open economy

The barter of quality content in exchange for viewership crosses country borders. In particular, the domestic nontraditional sector exports services and hires time input from foreign residents without a record in the current account. Quantifying the volume of such transactions can add to our understanding of trade in services.

3.3.2 Corporate finance

The model can be extended to form an alternative valuation of firms providing digital platforms than the those calculated based on discounted cash flows.

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Appendix A

Model Appendix to Chapter 1

In this section, I detrend the benchmark model in the paper and list the set of first-order conditions needed to compute the transition path.

A.1 The benchmark model

A.1.1 Firm problem

$$
\begin{aligned}
&\max \sum_{t=0}^{\infty} p_{it} D_t^{io} \left(1-\tau_{dt}\right) \\
&D_t^{io} = \sum_{j=u,r} \left[\left(1-\tau_{jt}^{p}\right)\left(p_{jt}^{io}\left(Y_{jt}^{io}-\delta_T K_{T,jt}^{io}-X_{I,jt}^{io}\right)-w_{jt}L_{jt}^{io}\right)\right. \\
&\qquad \left. -p_{jt}^{io}\left(K_{T,jt+1}^{io}-K_{T,jt}^{io}\right)\right]-\left(1-\tau_{it}^{p}\right)p_{jt}^{io}X_{M,t}^{io} \\
&K_{I,jt+1}^{io} = \left(1-\delta_I\right)K_{I,jt}^{io}+X_{I,jt}^{io} \\
&M_{t+1}^{io} = \left(1-\delta_M\right)M_t^{io}+X_{M,t}^{io}
\end{aligned}
$$

A.1.2 Household problem

The household's problem can be divided into two problems. Solving backward, the household first allocates resources across periods. Then within each period, the household decides on consumption between sectors (i.e., goods and services) and between country-specific varieties sourced home and abroad.

Dynamic problem

$$
\max \sum_{t=0}^{\infty} \beta^t N_{it}\left[\log\left(c_{it}\right)+\psi\log\left(1-l_{it}\right)\right]
$$

$$(\lambda p_{it} N_{it}) \qquad P_{it} c_{it} + \sum_o P_{it} \bar{c}_{it}^{io}$$
$$\leq w_{it} l_{it} + S_t (d_t + v_t)$$
$$- \frac{N_{it+1}}{N_{it}} S_{t+1} v_t + \frac{N_{it+1}}{N_{it}} b_{it+1} - \left(1 + r_t^b\right) b_{it}$$

Static problem

$$\max \quad c_{it}$$
$$c_{it} = \left[\sum_{o=g,s} (\omega^o)^{\frac{1}{\zeta}} (c_{it}^o + \bar{c}_{it}^o)^{\frac{\zeta-1}{\zeta}} \right]^{\frac{\zeta}{\zeta-1}}$$
$$c_{it}^o = \left[\theta^{io} (c_{it}^{io})^{\frac{\rho-1}{\rho}} + \theta^{jo} \left(c_{it}^{jo}\right)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}$$
$$c_{it}^{jo} = \left[\left(1 - \lambda_i^{jo}\right) \left(c_{it}^{jo,F}\right)^{\frac{\varrho-1}{\varrho}} + \lambda_i^{jo} \left(c_{it}^{jo,T}\right)^{\frac{\varrho-1}{\varrho}} \right]^{\frac{\varrho}{\varrho-1}}$$
$$\sum_{o=g,s} P_{it}^o (c_{it}^o + \bar{c}_{it}^o) = P_{it} c_{it}$$
$$\sum_{j=u,r} P_{it}^{jo} c_{it}^{jo} = P_{it}^o c_{it}^o$$
$$p_{it}^{jo} c_{it}^{jo,F} + p_{it}^{jo,T} c_{it}^{jo,T} = P_{it}^{jo} c_{it}^{jo}$$

A.2 Model detrended

A.2.1 Balanced growth path

Assume in equilibrium, the economy admits a balanced growth path, along which TFPs of all sectors grow at rate γ_A, and the population in the U.S. and the rest of the world grow at η. Then in equilibrium, per capita output, capital, and wage grow at γ_y,

$$\gamma_y = \left\{ (1 + \gamma_A) (1 + \eta)^\phi \right\}^{\frac{1}{(1-\phi)(1-\alpha_T-\alpha_I)}} - 1$$

A.2.2 Detrend

Along the balanced growth path, the detrendded value characterizes each variable as their deviations from the levels predicted by the long-term trend. The detrended variables are obtained by dividing the original ones at the per capita and the aggregate levels by $(1 + \gamma_y)^t$ and $(1 + \gamma_y)^t (1 + \eta)^t$, respectively.

A.2.3 Model with detrended variables

In this section, problems involving intertemporal choices are rewritten with detrended variables denoted with $\hat{\cdot}$.

Firm problem

$$\max \sum_{t=0}^{\infty} p_{it} (1+\eta)^t (1+\gamma_y)^t \hat{D}_t^{io} (1-\tau_{dt})$$

$$\hat{D}_t^{io} = \sum_{j=u,r} \hat{N}_{jt} \left[\left(1-\tau_{jt}^p\right) \left(p_{jt}^{io} \left(\hat{y}_{jt}^{io} - \delta_T \hat{k}_{T,jt}^{io} - \hat{x}_{I,jt}^{io} \right) - \hat{w}_{jt} l_{jt}^{io} \right) \right.$$
$$\left. - p_{jt}^{io} \left(\hat{N}_{jt+1}/\hat{N}_{jt} (1+\eta)(1+\gamma) \hat{k}_{T,jt+1}^{io} - \hat{k}_{T,jt}^{io} \right) \right] - (1-\tau_{it}^p) p_{jt}^{io} \hat{X}_{M,t}^{io}$$

$$\hat{k}_{I,jt+1}^{io} = \left[(1-\delta_I) \hat{k}_{I,jt}^{io} + \hat{x}_{I,jt}^{io} \right] \frac{\hat{N}_{I,jt}^{io}/\hat{N}_{I,jt+1}^{io}}{(1+\gamma)(1+\eta)}$$

$$\hat{M}_{t+1}^{io} = \left[(1-\delta_M) \hat{M}_t^{io} + \hat{X}_{M,t}^{io} \right] \frac{1}{(1+\gamma)(1+\eta)}$$

Household problem

Dynamic problem

$$\max \sum_{t=0}^{\infty} (\beta (1+\eta))^t \hat{N}_{it} \left[\log(\hat{c}_{it}) + \psi \log(1-l_{it}) \right]$$

$$\left(\lambda p_{it} \hat{N}_{it} (1+\eta)^t (1+\gamma)^t \right) \qquad P_{it}\hat{c}_{it} + \sum_o P_{it} \hat{\bar{c}}_{it}^{io}$$
$$\leq \hat{w}_{it} l_{it} + S_t \left(\hat{d}_t + \hat{v}_t \right) - \frac{\hat{N}_{it+1}}{\hat{N}_{it}} (1+\eta)(1+\gamma) S_{t+1} \hat{v}_t$$
$$+ \frac{\hat{N}_{it+1}}{\hat{N}_{it}} (1+\eta)(1+\gamma) b_{it+1} - \left(1+r_t^b\right) \hat{b}_{it}$$

A.2.4 First-order conditions

The first-order conditions used to compute the transition path are written in terms of the detrended variables.

$$\frac{p_{it}}{p_{it+1}} = \frac{1+\gamma_y}{\beta} \frac{P_{it+1}\hat{c}_{it+1}}{P_{it}\hat{c}_{it}}$$

$$\frac{\psi \hat{c}_{it}}{1-l_{it}} = \frac{\hat{w}_{it}}{P_{it}}$$

$$\frac{p_{it}}{p_{it+1}} = 1 + r_{t+1}^b$$

$$\frac{p_{it}}{p_{it+1}} = \frac{\hat{d}_{t+1} + \hat{v}_{t+1}}{\hat{v}_t}$$

$$\frac{p_{it}^{io}}{p_{it}^{jo}} = \left(\frac{\theta^{io}}{\theta^{jo}}\right)^{\frac{1}{\rho}} \left(\frac{C_{it}^{io}}{C_{it}^{jo}}\right)^{-\frac{1}{\rho}}$$

$$p_{it}^{o} = \left[\sum_{\tilde{i}=u,r} \theta^{\tilde{i}o} \left(p_{it}^{\tilde{i}o}\right)^{1-\rho_C}\right]^{\frac{1}{1-\rho_C}}$$

$$\frac{P_{it}^{g}}{P_{it}^{s}} = \left(\frac{\omega^g}{\omega^s}\right)^{\frac{1}{\zeta}} \left(\frac{c_{it}^{g} + \bar{c}_i^g}{c_{it}^{s} + \bar{c}_i^s}\right)^{-\frac{1}{\zeta}}$$

$$P_{it} = \left[\sum_{o=g,s} \omega^o \left(P_{it}^{o}\right)^{1-\zeta}\right]^{\frac{1}{1-\zeta}}$$

$$\hat{w}_{jt} l_{jt}^{io} = (1-\phi)(1-\alpha_T-\alpha_I)\, p_{jt}^{io} \hat{y}_{jt}^{io}$$

$$\frac{p_{it}}{p_{it+1}} \frac{1-\tau_{dt}}{1-\tau_{dt+1}} \frac{p_{jt}^{io}}{p_{jt+1}^{io}} = \left(1-\tau_{jt+1}^{p}\right)\left((1-\phi)\,\alpha_T \frac{\hat{y}_{j,t+1}^{io}}{\hat{k}_{T,t+1}} - \delta_T\right) + 1$$

$$\frac{p_{it}}{p_{it+1}} \frac{1-\tau_{dt}}{1-\tau_{dt+1}} \frac{p_{jt}^{io}}{p_{jt+1}^{io}} \frac{1-\tau_t^{p}}{1-\tau_{t+1}^{p}} = (1-\phi)\,\alpha_I \frac{\hat{y}_{j,t+1}^{io}}{\hat{k}_{I,t+1}} - \delta_I + 1$$

$$\frac{p_{it}}{p_{it+1}} \frac{1-\tau_{dt}}{1-\tau_{dt+1}} \frac{p_{it}^{io}}{p_{it+1}^{io}} \frac{1-\tau_t^{p}}{1-\tau_{t+1}^{p}} = \phi \frac{\sum_{j=u,r} \hat{N}_{jt} p_{jt+1}^{io} \hat{y}_{j,t+1}^{io}}{p_{it+1}^{io} M_{t+1}} + 1 - \delta_M$$

A.3 Other algebraic derivations

A.3.1 Firm's measured profit

$$\begin{aligned} NIPA\ profit &= \sum_{j=u,r}\left[\frac{r}{1-\tau^p} p_{jt}^{io}\hat{K}_{T,jt}^{io} + (r-\eta-\gamma_y)\, p_{jt}^{io}\hat{K}_{I,jt}^{io}\right] + (r-\eta-\gamma_y)\, p_{it}^{io}\hat{M}_t \\ &= \sum_{j=u,r}\left[\frac{r_t}{\left(1-\tau_{jt}^{p}\right)(\eta+\gamma_y+\delta_T)} p_{jt}^{io}\hat{X}_{T,jt}^{io} + (r_t-\eta-\gamma_y)\, p_{jt}^{io}\hat{K}_{I,jt}^{io}\right] \\ &\quad + (r_t-\eta-\gamma_y)\, p_{it}^{io}\hat{M}_t \end{aligned}$$

After-tax dividends

$$\hat{V}_0 = \sum_{t=0}^{\infty} \frac{1-\tau_d}{(1+r)^t} \hat{D}_t$$

$$\hat{D}_t = (r_t-\eta-\gamma_y)\left\{\sum_{j=u,r}\left[p_{jt}^{io} K_{T,jt}^{io} + (1-\tau_t^{p})\, p_{jt}^{io} K_{I,jt}^{io}\right] + p_{it}^{io}(1-\tau_t^{p})\, M^{io}\right\}$$

In the original variables,

$$\begin{aligned}V_0 = &\sum_{t=0}^{\infty}\left(\frac{(1+\eta)(1+\gamma_y)}{(1+r)}\right)^t \left(1-\tau_t^d\right)(r_t-\eta-\gamma_y)\\ &\times\left\{\sum_{j=u,r}\left[p_{jt}^{io}K_{T,jt}^{io}+(1-\tau_t^p)\,p_{jt}^{io}K_{I,jt}^{io}\right]+p_{jt}^{io}(1-\tau_t^p)\,M^{io}\right\}\\ =&\left(1-\tau_t^d\right)\left\{\sum_{j=u,r}\left[p_{jt}^{io}K_{T,jt}^{io}+(1-\tau_t^p)\,p_{jt}^{io}K_{I,jt}^{io}\right]+p_{it}^{io}(1-\tau_t^p)\,M^{io}\right\}\end{aligned}$$

Appendix B

Model Appendix to Chapter 3

In this appendix, the optimization problems are presented in details and the first-order conditions are derived to recover key equations in the second chapter of the thesis.

B.1 Optimization problems

The Lagrangian multiplier is specified in () for each irreducible constraint.

Household

$$\max_{c_{gs,t},h_t,l_t,b_{t+1}} \sum_{t=0}^{\infty} \beta^t \left[\log\left(c_{gs,t}\right) + \psi\theta_t \log l_t\right]$$

$$h_t + l_t = 1$$

$$(\lambda) \qquad \sum_{t=0}^{\infty} p_t c_{gs,t} \leq \sum_{t=0}^{\infty} p_t \left[w_t h_t + d_t\right]$$

Traditional Sector

$$\max_{h_{gs},x^d_{a,gs,t}} \sum_{t=0}^{\infty} p_t \left\{p_{gs,t} y_{gs,t} - w_t h_{gs,t} - p_{a,t} x^d_{a,gs,t}\right\}$$

$$a_{gs,t+1} = \left(1-\delta_a\right) a_{gs,t} + x^d_{a,t}$$

Nontraditional Sector

$$\max_{h_d,h_a,h_\theta,x_{k,\cdot}} \sum_{t=0}^{\infty} p_t \left\{p_{a,t}\left(A_{a,t} k^{\alpha_1}_{a,t} d^{\alpha_2}_t h^{1-\alpha_1-\alpha_2}_{a,t}\right)^{\mu} \left(l_t\left(\theta\right)\right)^{1-\mu}\right.$$

$$-w_t\left(h_{d,t} + h_{\theta,t} + h_{a,t}\right)$$

$$-\left(k_{a,t+1} - \left(1-\delta_k\right) k_{a,t}\right)$$

$$-\left(k_{\theta,t+1}-\left(1-\delta_{k}\right)k_{\theta,t}\right)$$

$$-\left(k_{d,t+1}-\left(1-\delta_{k}\right)k_{d,t}\right)\}$$

$$(p_t q_{\theta,t}) \qquad \theta_t=\left(A_{\theta,t}k_{\theta,t}^{\alpha_1}d_t^{\alpha_2}h_{\theta,t}^{1-\alpha_1-\alpha_2}\right)^{\mu}\left(l_t\left(\theta\right)\right)^{1-\mu}$$

$$(p_t q_{d,t}) \qquad x_{d,t}=\left(A_{d,t}k_{d,t}^{\alpha_1}d_t^{\alpha_2}h_{d,t}^{1-\alpha_1-\alpha_2}\right)^{\mu}\left(l_t\left(\theta\right)\right)^{1-\mu}$$

$$(\zeta_{d,t}) \qquad d_{t+1}=x_{d,t}+\left(1-\delta_d\right)d_t$$

B.2 Equilibrium conditions

Household

$$\left[\partial_{c_{gs,t}}\right] \qquad \beta^t\frac{1}{c_{gs,t}}=\lambda p_t$$

$$\left[\partial_{l_t}\right] \qquad \beta^t\frac{\psi\theta_t}{l_t}=\lambda p_t w_t$$

From the conditions above,

$$l_t\left(\theta_t\right)=\frac{\psi\theta_t c_{gs,t}}{w_t}$$

$$\frac{p_t}{p_{t+1}}=\frac{1}{\beta}\frac{c_{gs,t+1}}{c_{gs,t}}$$

Nontraditional Sector

$$\left[\partial_{h_{a,t}}\right] \qquad \frac{\mu\left(1-\alpha_1-\alpha_2\right)p_{a,t}x_{a,t}}{h_a}=w_t$$

$$\left[\partial_{h_{d,t}}\right] \qquad \frac{\mu\left(1-\alpha_1-\alpha_2\right)q_{d,t}x_{d,t}}{h_d}=w_t$$

$$\left[\partial_{h_{\theta,t}}\right] \qquad \frac{\mu\left(1-\alpha_1-\alpha_2\right)q_{\theta,t}\theta_t}{h_{\theta,t}}=w_t$$

$$\left[\partial_{k_{a,t+1}}\right] \qquad p_t=p_{t+1}\left[\left(1-\delta_k\right)+\mu\alpha_1\frac{p_{a,t+1}x_{a,t+1}}{k_{a,t+1}}\right]$$

$$\left[\partial_{k_{d,t+1}}\right] \qquad p_t=p_{t+1}\left[\left(1-\delta_k\right)+\mu\alpha_1\frac{q_{d,t+1}x_{d,t+1}}{k_{d,t+1}}\right]$$

$$\left[\partial_{k_{\theta,t+1}}\right] \qquad p_t=p_{t+1}\left[\left(1-\delta_k\right)+\mu\alpha_1\frac{q_{\theta,t+1}\theta_{t+1}}{k_{\theta,t+1}}\right]$$

$$\left[\partial_{d_{t+1}}\right] \qquad \zeta_{d,t} = \zeta_{d,t+1}\left(1-\delta_d\right) + \mu\alpha_2 p_{t+1}\frac{p_{a,t+1}x_{a,t+1} + q_{\theta,t+1}\theta_{t+1} + q_{d,t+1}x_{d,t+1}}{d_{t+1}}$$

$$\left[\partial_{x_{d,t}}\right] \qquad p_t q_{d,t} = \zeta_{d,t}$$

Combining the two conditions above gives equation (6) in the chapter,

$$\frac{p_t}{p_{t+1}}q_{d,t} = q_{d,t+1}\left(1-\delta_d\right) + \mu\alpha_2\frac{p_{a,t+1}x_{a,t+1} + q_{\theta,t+1}\theta_{t+1} + q_{d,t+1}x_{d,t+1}}{d_{t+1}}$$

$$\left[\partial_{\theta_t}\right] \qquad q_{\theta,t} = \frac{\left(1-\mu\right)\left(p_{a,t}x_{a,t} + q_{d,t}x_{d,t} + q_{\theta,t}\theta_t\right)}{l_t}\frac{\partial}{\partial\theta_t}l_t\left(\theta_t\right)$$

Substitute

$$\frac{\partial}{\partial\theta_t}l_t\left(\theta_t\right) = \frac{l_t}{\theta_t}$$

into the previous condition gives equation (4).