Gains from Trade with Competitive Effects*

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Draft

Abstract

This article studies the domestic gains from trade using a model with variable markups and multiple sectors in an Input-Output structure. I find the domestic gains from trade are larger with variable markups, and decrease the higher the cost pass-through. Computing the model to the US in 1997 and 2007, I quantify the gains from trade to be 6.1%. In this period, the pro-competitive effect dominates the anti-competitive effects, with markups decreasing in all markets. This is a first approximation to general equilibrium models with both competitive effects of imports, and their interaction with the gains from trade.

*I am indebted to Robert Johnson for his guidance. All errors are my own.

1 Introduction

Is trade always beneficial for competition, or can it increase markups? Can imports increase domestic distortions? How are the gains from trade affected by changes in markups? In this article I present a model incorporating both pro-competitive and anti-competitive effects of trade, and discuss its aggregate effects. By anti-competitive effects I mean circumstances when an increase in imports raises domestic markups, with pro-competitive effects lowering markups instead.

I propose a model featuring both effects in a multi-sector small open economy with inputs in production, trade, and Input-Output linkages. To address the welfare implications of competitive effects I estimate this model matching data for 1997 and 2007. I find that the increase in imports experienced in this period led to a 6.1% increase in real consumption. The entry of imports also reduced manufacturing markups -5.5% and decreased markups in non-manufacturing -0.4%.

To quantify the contribution of variable markups, I re-calibrate the model to higher cost pass-through. Changing cost pass-through from 50% to 100% reduces the welfare gain to 5.1%. Put differently, allowing for variable markups increases the gains from trade by 20%. Different pass-through calibrations also affect production in non-evident ways, as more variable markups muffle shocks.

Trade is beneficial because it expands consumption possibilities beyond a country's own production, in spite it might hurt particular sectors. But trade is also beneficial because it increases competition, in what is called the pro-competitive effect of trade. The welfare contribution of this competitive channel is not yet clear, as discussed in Arkolakis et al. [2019]. At the same time, empirical studies on trade liberalization episodes suggest that, just as there are losers in specialization, trade also has a downside in domestic competition, an anti-competitive effect of trade. See for example Martynov and Zhang [2023], Impullitti and Kazmi [2023], De Loecker et al. [2016], Amiti and Konings [2007]

The existence of both a pro-competitive and anti-competitive effects means an increase in imports has contradictory consequences on markups. The pro-competitive effect is the reduction of domestic markups in markets receiving new imports. At the same time, markups downstream increase because the cost reduction is not entirely passed-through to buyers, the anti-competitive effect. Prices decrease on both markets, but distortions move in opposite directions. Importantly, even though prices go down, the anti-competitive effect operates on each downstream step, meaning the cost reduction does not cascade down the supply chain. In other words, the anti-competitive effect successively attenuates the cost reductions. In the end imports could both increase or decrease markups, depending on the structure of domestic transactions.

This mechanism highlights the interaction between trade and the Input-Output organization of production. By Input-Output structure I mean a framework where firms use output of other firms as their production inputs to produce; in turn selling part of the production as inputs to other firms, and another part to consumers. In particular, Baqaee and Farhi [2023] show how the Input-Output structure and market distortions affect the welfare gains from trade for a large class of models. The Input-Output structure is particularly relevant for competitive effects as it can give amplification to even modest changes in markups, as shown by Bridgman and Herrendorf [2023]. Although these studies attest to the importance of using the production loop when discussing the competitive effects of trade, they usually assume fixed distortions.

In this paper I use a model with variable markups, trade, and an Input-Output structure, to quantify the implications of these competitive effects. I contribute to the literature by including these distortions as equilibrium objects along the Input-Output structure, and compute the domestic welfare gains. Although variable markups and import competition are enough to create pro-competitive effects, the Input-Output structure is crucial for the anti-competitive effects, as well as for amplification along the domestic economy.

My work is based on the model proposed by Comin and Johnson [2022], removing sticky prices but adding multiple sectors. Although the multi-sector extension is necessary to distinguish anti-competitive effects from pro-competitive effects, most other elements necessary to explain the markup increase as a result of imports are already present there. My model is also related to Gopinath and Itskhoki [2010] and Gopinath et al. [2020] given the variable markup structure and role of pass-through on both, but I focus on cost pass-through and not exchange-rate pass-through.

In the next section I present some intuition on how markups affect the gains from trade. I describe the model in Section 3, and presents my estimates in Section 4, concluding in Section 5. A brief summary of the equilibrium can be found in Appendix 1.

2 Markups and the Gains from Trade

In this section I present the intuition on how markups link to the gains from trade in my model. I first present the main intuition in a one sector example, to then extend it to multiple sectors.

2.1 One-Sector Example

The Gains from Trade are the improvement in welfare countries reap from engaging in international trade. In my model, I will use real consumption as my welfare measure. For simplicity, I will start with a one-sector model.

Consider a model with two countries, Home (H) and Foreign (F), and only one industry. There is a unit continuum of varieties at Home, produced under monopolistic competition. Home firms produce using intermediate inputs and labor, and can sell their output as both consumption or intermediate inputs. Firms combine labor and intermediate inputs using a Cobb-Douglas production function. Prices for Home goods are set as some variable markup over marginal cost, where markups are inversely related to how relatively expensive the good is. I assume symmetric producers so prices across varieties are the same.

2.1.1 Gains from Trade with One Sector

In the setting presented, consumption is financed by wages and profits according to the usual resource constraint

$$P_{Ct}C_t = W_tL_t + \Pi_t + T_t \tag{1}$$

where C_t is real consumption, sold at price P_{Ct}. W_t are the wages paid to labor L_t, Π_t are firm profits, and T_t is the trade deficit. For clarity assume $T_t = 0$.

The wage bill is tied to production through labor demand, in this case

$$W_tL_t = (1-\alpha)\left(MC_t\right)Y_t \tag{2}$$

with output being produced as a Cobb-Douglas combination of labor and inputs $Y = ZL^{(1-\alpha)}M^{\alpha}$, and MC_t representing marginal costs. Firms will sell their production at Home or to the Foreign economy. As optimal pricing corresponds to markups times marginal costs, profits will take the form

$$\Pi_t = \frac{1}{\epsilon_{Ht}}P_{Ht}Y_{Ht} + \frac{1}{\epsilon_{Xt}}P_{Xt}X_t \tag{3}$$

where Y_{Ht} is the part of output sold within the Home economy at price P_H, facing elasticity ϵ_H. Likewise, Y_X is the part of output sold as exports at price P_X, facing elasticity ϵ_X. I can rewrite this expression as

$$\Pi_t = \frac{1}{\epsilon_{Ht}} P_{Ht} \left(Y_{Ht} + X_t\right) + \left(\frac{1}{\epsilon_{Xt}} P_{Xt} - \frac{1}{\epsilon_{Ht}} P_{Ht}\right) X_t \tag{4}$$

where the first term represents total production sold at Home prices, and the second term reflects the additional profits from pricing-to-market of exports. Combining equations $(1-2)$ and (4) gives

$$P_{Ct} C_t = (1-\alpha)\left(MC_t\right) Y_t + \frac{1}{\epsilon_{Ht}} P_{Ht} \left(Y_{Ht} + X_t\right) + \left(\frac{1}{\epsilon_{Xt}} P_{Xt} - \frac{1}{\epsilon_{Ht}} P_{Ht}\right) X_t \tag{5}$$

Using optimal pricing again, and expressing markups as functions of the demand elasticity $\mu_{Ht} = \frac{\epsilon_{Ht}}{\epsilon_{Ht}-1}$ I get an expression for real consumption as a function of markups

$$C_t = \left(1 - \frac{\alpha}{\mu_{Ht}}\right) \frac{P_{Ht}}{P_{Ct}} Y_t + \left(\frac{1}{\epsilon_{Xt}} P_{Xt} - \frac{1}{\epsilon_{Ht}} P_{Ht}\right) \frac{X_t}{P_{Ct}} \tag{6}$$

Equation (6) contains many familiar components of the gains from trade:

First, the terms of trade $\frac{P_{Ht}}{P_{Ct}}$ represent how expensive domestic production is with respect to consumption. This are part of the classical Ricardian gains from trade, where a surge in imports lowers P_C for a given P_H, increasing welfare.

Second, import competition changes production Y_t through three mechanisms: (a) changes in marginal costs due to input prices, which I will call cost gains from trade; (b) reallocation across factors of production M_t and L_t; and (c) changes in allocative efficiency due to input markups μ_{H_t}. I explore these channels in more depth in the following section.

Third, imports change the term $\left(1 - \frac{\alpha}{\mu_H}\right)$ through markups μ_{Ht}, which affects what share of output turns into domestic resources. For example, if only labor was used in production, $\alpha = 0$, all the value of production would be available to finance consumption.

And Fourth, there is a profit-shifting term, given by the price difference between exports than domestic prices. I will mostly abstract from this mechanism, both for simplicity but also because it is more related to what happens in the Foreign destination market.

Here markups will play two roles. First, lower markups decrease the term ruling how much of production turns into consumption $\left(1 - \frac{\alpha}{\mu_H}\right)$, as lower markups mean lower profits $\Pi = \left(1 - \frac{1}{\mu_H}\right) Y$. At the same time, lower markups indirectly help increase output because domestic input prices are lower.

2.1.2 Consumption and Markups

To unpack the effect of markups in production, I use first order approximations of the model presented in section 3. I also abstract from the pricing-to-market term, to focus on import competition and markups. Starting with equation (6) I will have

$$\hat{c}_t = \frac{\alpha}{\mu_{H0} - \alpha}\hat{\mu}_{Ht} + \hat{p}_{Ht} - \hat{p}_{Ct} + \hat{y}_t \tag{7}$$

where terms $\hat{x}$ are the log deviations from baseline. As presented before, we will have the first term directly linked to markups, a second term related to the terms of trade, and a last term encompassing the effects on production.

To disentangle the term linked to production, assume for now both productivity and labor are exogenous. Then changes in production would be ruled by changes in input use

$$\hat{y}_t = \alpha \hat{m}_t \tag{8}$$

manipulating input demand $P_{Mt}M_t = \alpha \left(MC_t\right) Y_t$ and expressing optimal pricing as $MC_t = \frac{P_H}{\mu_H}$ I get an expression for inputs linked to markups

$$\hat{m}_t = \left(p_{Ht} - p_{Mt}\right) + y_t - \mu_{Ht} \tag{9}$$

this is, for a given level of output and relative prices, an increase in markups lowers input use. Now combine (9) and (12) to get

$$\hat{y} = \frac{\alpha}{1-\alpha}\left(p_H - p_M\right) - \frac{\alpha}{1-\alpha}\mu_H \tag{10}$$

where the first term gives the output response to changes in the price of inputs, and the second reflects the how markups can strain production. Combining equations (7) and (10) delivers a formula for the evolution of real consumption in terms of markups and prices

$$\hat{c}_t = \frac{\alpha}{\mu_{H0} - \alpha}\hat{\mu}_{Ht} + (\hat{p}_{Ht} - \hat{p}_{Ct}) + \frac{\alpha}{1-\alpha}(\hat{p}_{Ht} - \hat{p}_{Mt}) - \frac{\alpha}{1-\alpha}\mu_{Ht} \tag{11}$$

Equation (11) disentangles the effects on welfare. The first term $\frac{\alpha}{\mu_{H0}-\alpha}\hat{\mu}_{Ht}$ gives us the increase in resources for consumers from larger profits. The second $(\hat{p}_{Ht} - \hat{p}_{Ct})$ gives the Ricardian gains. The third term $\frac{\alpha}{1-\alpha}(p_H - p_M)$ gives the cost-channel gains from less expensive inputs. And the final term $-\frac{\alpha}{1-\alpha}\mu_H$ gives us the allocative efficiency change due to changes in the markup distortion. Rearranging

$$\hat{c}_t = \left(\frac{\alpha}{\mu_{H0} - \alpha} - \frac{\alpha}{1-\alpha}\right)\hat{\mu}_{Ht} + (\hat{p}_{Ht} - \hat{p}_{Ct}) + \frac{\alpha}{1-\alpha}(\hat{p}_{Ht} - \hat{p}_{Mt}) \tag{12}$$

Equation (12) shows how a decrease in markups will always increase welfare. This because for any change in markups the loss in resources from markups will always be smaller than the resources gained from improving efficiency. This will always be case as long as markups at baseline are above one $\mu_{H0} > 1$, making $\frac{\alpha}{\mu_{H0}-\alpha} < \frac{\alpha}{1-\alpha}$

2.1.3 Domestic Expenditure Shares

Equation (12) can also be rewritten in terms of the domestic expenditure shares, which Arkolakis et al. [2012] identify as sufficient statistics for welfare. With the preferences and technology I will formally present in the next section, the change in prices can be rewritten as

$$(\hat{p}_{Ht} - \hat{p}_{Ct}) = -\frac{1}{\sigma - 1}\lambda^{C} \tag{13}$$

$$(p_{H} - p_{M}) = -\frac{1}{\sigma - 1}\lambda^{M} \tag{14}$$

Likewise, the change in markups will be linked to the change in demand elasticities, in turn linked to expenditure shares such that

$$\hat{\mu}_{Ht} = \mu_{H0}\frac{1}{\sigma - 1}\left(\frac{C_{H0}}{Y_{H0}}\hat{\lambda}^{C}_{Ht} + \frac{M_{H0}}{Y_{H0}}\hat{\lambda}^{M}_{Ht}\right) \tag{15}$$

this is, larger expenditure shares increase markups, diminishing real consumption. Combining equations $(12 - 15)$ yields a formula for real consumption as a function of domestic expenditure shares

$$\hat{c}_t \;\; = \;\; -\frac{1}{\sigma - 1}\left[J_1\mu_{H0}\left(\frac{C_{H0}}{Y_{H0}}\hat{\lambda}^{C}_{Ht} + \frac{M_{H0}}{Y_{H0}}\hat{\lambda}^{M}_{Ht}\right) + \hat{\lambda}^{C}_{Ht} + \frac{\alpha}{1-\alpha}\hat{\lambda}^{M}_{Ht}\right] \tag{16}$$

with $J_1 = \left(\frac{\alpha}{1-\alpha} - \frac{\alpha}{\mu_{H0}-\alpha}\right) > 0$. In equation (16), the first term inside brackets represents the contribution of variable markups to welfare, in terms of the sufficient statistic. The remaining terms represent the Ricardian gains from trade, and the cost gains from trade. Once again, variable markups increase the welfare gains from trade, now expressed in terms of domestic expenditure shares.

2.2 Multi-Sector Example

One advantage of the one-sector example is that the price of inputs is the same as the price paid for domestic inputs. However, and for the same reason, the markup-increasing and markup-decreasing effects will superpose, as there is only one markup suffering the pro-competitive and anti-competitive effects of imports.

To circumvent this limitation, I derive a multi-sector version of equation (12), following a similar procedure. The multi-sector version of equation (7) will be

$$\hat{c}_t = \sum_s \kappa_s \left(\frac{\alpha_s}{\mu_{Hs0} - \alpha_s} \hat{\mu}_{Hst} + \hat{p}_{Hst} - \hat{p}_{Cst} + \hat{y}_s \right) \tag{17}$$

with κ_s positive weights corresponding to consumption resources from each sector at baseline.

However, because inputs used are no longer priced the same as output, the analog expression to equation 10 will not allow the same manipulations

$$\hat{y}_s = \frac{\alpha_s}{1 - \alpha_s} \left(\hat{p}_{Hst} - \sum_{s'} \frac{\alpha_{s's}}{\alpha_s} \hat{p}_{Ms'st} - \hat{\mu}_{Hst} \right) \tag{18}$$

where $\sum_{s'} \alpha_{s's} = \alpha_s$. The analog to equation (12) is similarly achieved by plugging the effect of production

$$\hat{c}_t = \sum_s \kappa_s \left(J_s \hat{\mu}_{Hst} + \hat{p}_{Hst} - \hat{p}_{Cst} + \frac{\alpha_s}{1 - \alpha_s} \left(\hat{p}_{Hst} - \sum_{s'} \frac{\alpha_{s's}}{\alpha_s} \hat{p}_{Ms'st} \right) \right) \tag{19}$$

And in terms of domestic expenditure shares, the analog of equation (16) is

$$\hat{c}_t = -\frac{1}{(\sigma-1)}\sum_s \kappa_s \left(J_s^C \hat{\lambda}_{Hst}^C + J_s^M \hat{\lambda}_{Hst}^M + \hat{\lambda}_{Hst}^C + \frac{\alpha_s}{1-\alpha_s}\left(\sum_{s'}\left(\frac{\alpha_{s's}}{\alpha_s}\right)\hat{\lambda}_{Hs'st}^M\right)\right) \quad (20)$$

Where now $J_s^C = J_s \mu_{Hs0}\frac{C_{Hs0}}{Y_{Hs0}}$ and $J_s^C = J_s \mu_{Hs0}\frac{M_{Hs0}}{Y_{Hs0}}$ But ultimately the expression looks similar to the one sector case[1].

Combined, these examples provide the main intuition of the model: variable markups increase real consumption. This intuition is true in the one-sector and the multi-sector model. However, the previous analysis required some simplifying assumptions, and is based in log-linear approximations. To confirm my intuition holds in general equilibrium, and when exactly estimated, I present the full model in section 3, and the estimated results in section 4.

3 Model

3.1 Set Up

This section presents a small open economy multi-sector model with variable markups. It features inputs in production, multiple sectors intertwined in an Input-Output structure, and trade in both intermediate and final goods. Variable markups arise from using Kimball technology aggregation and preferences over varieties. The model is static, and prices are flexible. There

[1]Here I use the fact that the double sum of prices will net out $\sum_s p_{Hst} - \sum_s \sum_{s'}\left(\frac{\alpha_{s's}}{\alpha_s}\right)\hat{p}_{Hs't} = 0$

will be two kinds agents, consumers and firms. I present their optimization problems below.

3.1.1 Consumer

A representative consumer has preferences over consumption C_t and labor supply L_t, typified as

$$U\left(C_t, L_t\right) \quad = \quad u\left(C_t, L_t\right) = \frac{C_t^{1-\rho}}{1-\rho} - \varsigma \frac{L_t^{\psi+1}}{\psi+1} \tag{21}$$

where ρ governs the marginal utility of labor, ψ is the inverse of the Frisch elasticity of labor supply, and ς is a scaling parameter.

Aggregate consumption C_t is a basket of final goods C_{st} from each sector $s \in \{1, \ldots, S\}$, with CES preferences over sector-aggregated goods

$$C_t \quad = \quad \left(\sum_s \zeta_s^{\frac{1}{\vartheta}} C_{st}^{\frac{\vartheta-1}{\vartheta}} \right)^{\frac{\vartheta}{\vartheta-1}} \tag{22}$$

where ζ_s is a sector-bias parameter, and ϑ is the elasticity of substitution of consumption across sectors.

Consumption from each sector C_{st} is a non-homothetic combination of infinite differentiated varieties $i \in [0, 1]$ following the definition by Kimball [1995], which aggregates consumption varieties produced at Home C_{Hist}, and consumption varieties produced in Foreign economies C_{Fist}

$$\nu_s \int_0^1 \Upsilon\left(\frac{C_{Hist}}{\nu_s C_{st}}\right) di + (1-\nu_s)\int_0^1 \Upsilon\left(\frac{C_{Fist}}{(1-\nu_s)\, C_{st}}\right) di \quad = \quad 1 \tag{23}$$

where function $\Upsilon(.)$ must satisfy $\Upsilon(1) = 1$, $\Upsilon'(.) > 0$, and $\Upsilon''(.) < 0$, and ν_s is the home bias parameter. I adopt the definition of the $\Upsilon(.)$ aggregator proposed by Klenow and Willis [2016]

$$\Upsilon(x_s) \quad = \quad 1 + (\sigma_s - 1)\exp\left(\frac{1}{\epsilon_s}\right)\epsilon^{\frac{\sigma_s}{\epsilon_s - 1}}\left(\Gamma\left(\frac{\sigma_s}{\epsilon_s}, \frac{1}{\epsilon_s}\right) - \Gamma\left(\frac{\sigma_s}{\epsilon_s}, \frac{x_s^{\frac{\epsilon_s}{\sigma_s}}}{\epsilon_s}\right)\right) \tag{24}$$

where $\Gamma(u,z) = \int_z^\infty s^{u-1}e^{-s}ds$ is the incomplete gamma function, and $\Upsilon(.)$ has sector-specific parameters σ_s and ϵ_s, with $\sigma_s > 1$ and $\epsilon_s > 0$. Defining preferences this way delivers variable elasticity of demand ϵ_{Hist} for each variety at Home.

Consumers finance expenditure through wages W_t earned from renting their labor L_t, and by collecting profits Π_t from the firms they own. The nominal flow resource constraint is then

$$P_{Ct}C_t \quad = \quad W_t L_t + \Pi_t + T_t \tag{25}$$

where P_{Ct} is the price of consumption, and T_t is the trade deficit, here an exogenous transfer of resources from the rest of the world.

Given prices $\{P_{Ct}, P_{Cst}, P_{Hist}, P_{Fist}, W_t\}$ and foreign transfer $\{T_t\}$, the consumer chooses consumption $\{C_t, C_{st}, C_{Hist}, C_{Fist}\}$ and labor supply $\{L_t\}$

to maximize equation (21) subject to $(22-25)$.

The optimal decision of consumption and labor is thus determined by consumption prices P_{Ct} and wages W_t

$$C_t^{-\rho}\frac{W_t}{P_{Ct}} = \varsigma L_t^{\psi} \tag{26}$$

where the sector composition of the consumption basket C_{st} depends on the ratio of prices $\frac{P_{Cst}}{P_{Ct}}$, and parameters ζ_s and ϑ

$$C_{st} = \zeta_s\left(\frac{P_{Cst}}{P_{Ct}}\right)^{-\vartheta} C_t \tag{27}$$

Aggregate consumption prices are determined by sector consumption prices, and again parameters ζ_s and ϑ

$$P_{Ct} = \left(\sum_s \zeta_s P_{Cst}^{1-\vartheta}\right)^{\frac{1}{1-\vartheta}} \tag{28}$$

The price of consumption from each sector is a weighted average of prices from each source

$$P_{Cst} = P_{Hst}\frac{C_{Hst}}{C_{st}} + P_{CFst}\frac{C_{Fst}}{C_{st}}$$

Optimal demand for consumption goods of each source, Home and Foreign, is also determined by the corresponding price ratios $\frac{P_{Hst}}{P_{Cst}}$ and $\frac{P_{CFst}}{P_{Cst}}$, but now nests inside function $\Psi(y) = \Upsilon'^{-1}(y) = \left(1 + \epsilon_s \ln\left(\frac{\sigma_s - 1}{\sigma_s y}\right)\right)^{\frac{\sigma_s}{\epsilon_s}}$

$$C_{Hist} = \nu_s \Psi\left(D_{Cst} \frac{P_{Hist}}{P_{Cst}}\right) C_{st} \tag{29}$$

$$C_{Fist} = (1 - \nu_s) \Psi\left(D_{Ct} \frac{P_{Fist}}{P_{Cst}}\right) C_{st} \tag{30}$$

where D_{Cst} is a demand index factor

$$D_{Cst} = \int_0^1 \Upsilon'\left(\frac{C_{Hist}}{\nu_s C_{st}}\right) \frac{C_{Hist}}{C_{st}} di + \int_0^1 \Upsilon'\left(\frac{C_{Fist}}{(1 - \nu_s) C_{st}}\right) \frac{C_{Fist}}{C_{st}}$$

where prices for domestic varieties P_{Hist} are determined by each firm.

3.1.2 Firms

Firms are monopolistic producers of differentiated goods. Each firm produces variety i in sector s combining labor L_{ist} and inputs M_{ist} to produce gross output quantity Y_{ist} of variety i. The production technology is Cobb-Douglas

$$Y_{ist} = Z_{st} L_{ist}^{1-\alpha_s} M_{ist}^{\alpha_s} \tag{31}$$

where M_{ist} is a composite of input varieties from Home and Foreign. Here total factor productivity Z_{st} and the production elasticity α_s are sector specific.

The composite of inputs M_{ist} is a CES combination of inputs from each sector

$$M_{ist} = \left(\sum_{s'} \left(\frac{\alpha_{s's}}{\alpha_s}\right)^{\frac{1}{\kappa_s}} M_{s'ist}^{\frac{\kappa_s - 1}{\kappa_s}}\right)^{\frac{\kappa_s}{\kappa_s - 1}} \tag{32}$$

with κ_s representing substitution of inputs across sectors, and $\alpha_{s's}$ a sector-by-sector parameter, where $\sum_{s'} \alpha_{s's}$ [2].

In similar fashion as before, varieties from Home and Foreign are aggregated using Kimball technology

$$\xi_{s's} \int_0^1 \Upsilon\left(\frac{M_{Hjs'ist}}{\xi_{s's} M_{s'ist}}\right) dj + (1 - \xi_{s's}) \int_0^1 \Upsilon\left(\frac{M_{Fjs'ist}}{(1 - \xi_{s's})\, M_{s'ist}}\right) dj = 1 \tag{33}$$

where $\Upsilon(.)$ is defined as before, and $\xi_{s's}$ is the home bias of firms from sector s when buying inputs from sector s'. $M_{Hjs'ist}$ and $M_{Fjs'ist}$ are domestic demands, where variety j of sector s' sells to firm i of sector s, produced at Home and Foreign. $M_{s'ist}$ is then demand of inputs sold by sector s' to firms i in sector s.

There are no fixed costs, so profits are the difference between prices and marginal costs times gross output.

$$\Pi_{ist} = (P_{Hist} - MC_{ist})\, Y_{ist} \tag{34}$$

To have an explicit expression of marginal costs MC_{ist}, I split the firm problem in cost minimization first and profit maximization second. Cost are determined

[2]Note that if $\kappa = 1$ we would have $M_{ist} = \prod_{s'} (M_{s'ist})^{\frac{\alpha_{s's}}{\alpha_s}}$ which makes $Y_{ist} = Z_{st} L_{ist}^{1-\alpha_s} \prod_{s'} (M_{s'ist})^{\alpha_{s's}}$.

by the cost function $C(.)$

$$C(W_t, P_{Mist}) = W_t L_{ist} + P_{Mist} M_{ist} \tag{35}$$

so for given prices $\{P_{Mist},\ P_{Hist},\ P_{Fist},\ P_{Hjs'ist}\}$, marginal costs $\{MC_{it}\}$ are determined by choosing the demand of inputs $\{M_{ist},\ M_{Hist},\ M_{Fist},\ M_{Hjs'ist}\}$ and labor $\{L_{ist}\}$ that minimize (35) subject to $(31-33)$. With the optimal cost function, the firm maximizes profits (34) subject to cost function (35).

Optimal demands for labor L_{ist} and total inputs M_{ist} are then conditional on firm output Y_{ist}, the marginal costs of each variety MC_{ist} and the elasticities of production α_s, given wages W_t and input prices P_{Mist}

$$W_t L_{ist} = (1-\alpha_s) Y_{ist} MC_{ist} \tag{36}$$

$$P_{Mist} M_{ist} = \alpha_s Y_{ist} MC_{ist} \tag{37}$$

Marginal cost for firms in sector s is also a function of wages W_t and the price of the input basket P_{Mist}, as well as sector productivity Z_{st} and production elasticity α_s

$$MC_{ist} = Z_{st}^{-1} (1-\alpha_s)^{-(1-\alpha_x)} \alpha_s^{-\alpha_s} W_t^{(1-\alpha_s)} P_{Mist}^{\alpha_s} \tag{38}$$

Each variety i of sector s could have a different demand for inputs from each sector s' $M_{s'is}$, determined by the total demand for inputs in sector s M_{ist}, the production parameters $\frac{\alpha_{s's}}{\alpha_s}$, the price ratio for each input with respect to the basket $\frac{P_{Ms'ist}}{P_{Mist}}$, and elasticity of substitution κ_s

$$M_{s'ist} = M_{ist}\left(\frac{\alpha_{s's}}{\alpha_s}\right)\left(\frac{P_{Ms'ist}}{P_{Mist}}\right)^{-\kappa_s} \tag{39}$$

with corresponding CES prices for the input basket

$$P_{Mist} = \left(\sum_{s'}\left(\frac{\alpha_{s's}}{\alpha_s}\right)P_{Ms'ist}^{1-\kappa_s}\right)^{\frac{1}{1-\kappa_s}} \tag{40}$$

Like in consumption, demand for inputs from each source are determined by the ratio of prices $\frac{P_{His't}}{P_{Ms'ist}}$ times the demand factor $D_{Ms'st}$ as arguments of function $\Psi(.)$

$$M_{Hs'ist} = \xi_{s's}\Psi\left(D_{Ms'ist}\frac{P_{Hs't}}{P_{Ms'ist}}\right)M_{s'ist} \tag{41}$$

$$M_{Fs'ist} = (1-\xi_{s's})\,\Psi\left(D_{Ms'ist}\frac{P_{MFs't}}{P_{Ms'ist}}\right)M_{s'ist} \tag{42}$$

where the price of inputs from each sector s' to variety i in sector s is the weighted average across sources

$$P_{Ms'ist} = \int_0^1 P_{MHs'ist}\frac{M_{Hs'ist}}{M_{s'ist}}di + \int_0^1 P_{MFs'ist}\frac{M_{Fs'ist}}{M_{s'ist}}di \tag{43}$$

P_{Hist} is the optimal pricing decision of each firm, which results in a markup over marginal costs

$$P_{Hist} = \frac{\epsilon_{Hist}}{\epsilon_{Hist}-1}MC_{ist} \tag{44}$$

with ϵ_{Hist} the variable elasticity of demand faced by monopolistic firms i in sector

s.

3.1.3 Exports, Imports, Market Clearing, and Demand

Domestic firms i serve Foreign demand of final goods X_{ist}, where preferences over varieties are also CES

$$X_{ist} = \left(\frac{P_{Hist}}{P_{Hst}}\right)^{-\varepsilon_{Xs}} X_{st} \tag{45}$$

with ε_X ruling over substitution across varieties, and aggregate demand for exports X_{st} is also a CES bundle

$$X_{st} = \left(\frac{P_{Hst}}{P^*_{Cst}}\right)^{-\eta_{Xs}} C^*_{st} \tag{46}$$

with η_X ruling over substitution across sources, P^*_{Cst} the price of Foreign consumption, and C^*_{st} the level of foreign consumption demand.

An analog price setting to Home prices occurs at Foreign, from the which domestic firms import. Import prices at Home are Foreign prices times the iceberg trade costs $P_{CFist} = \tau_{Cst} P^*_{Fist}$. In addition, P^*_{Fist} is markup over marginal costs in terms of Foreign currency, so it requires multiplying by the nominal exchange rate e_t to convert to Home currency $P^*_{CFist} = e_t \frac{\epsilon_{Fist}}{\epsilon_{Fist}-1} MC^*_{ist}$ where the elasticities are analog to the domestic case

$$\varepsilon_{Fist} = \varepsilon^C_{Fist} \frac{C_{Fist}}{C_{Fist} + \sum_{s'} M_{Fis'st}} + \sum_{s'} \varepsilon^M_{Fis'st} \frac{M_{Fis'st}}{C_{Fist} + \sum_{s'} M_{Fis'st}} \tag{47}$$

The nominal exchange rate is defined as $e_t \equiv \frac{P_{Ct}}{P^*_{Ct}} q_t$, with the real exchange rate the ratio of marginal utilities of consumption $q_t = \left(\frac{C_t}{C_t^*}\right)^{-\rho}$. I bundle all other elements so pricing is markup over marginal costs, resulting in $MC_{CFst} = \tau_{Cst} e_t MC^*_{st}$ and $MC_{MFs'st} = \tau_{Ms't} e_t MC^*_{s'st}$.

With all these definitions and aggregations in the background, foreign prices will be determined as

$$P_{CFst} = \frac{\epsilon_{Fst}}{\epsilon_{Fst} - 1} MC_{Cst} \tag{48}$$

$$P_{MFs'st} = \frac{\epsilon_{Fst}}{\epsilon_{Fst} - 1} MC_{Ms'st} \tag{49}$$

Finally, market clearing for each variety i in sector s is achieved when its production equals the sum across all its uses

$$Y_{ist} = C_{Hist} + \int_0^1 M_{Hisjs't} dj + X_{ist} \tag{50}$$

and clearing for the labor market

$$L_t = \sum_s \int_0^1 L_{ist} di \tag{51}$$

3.1.4 Equilibrium

I will focus on the equilibrium where firms i are symmetric, collapsing to a representative firm per sector s. Given the values for $\{P_{CFst}$, $P_{MFs'st}$, Z_{st}, P^*_{Cst}, C^*_{st}, $T_t\}$, the equilibrium is a group of 8 sets of prices $\{P_{Hst}$, MC_{st}, P_{Ct}, P_{Cst}, P_{Mst}, $P_{Ms'st}$, P_{Xst}, $W_t\}$ and 15 sets of allocations $\{L_t$, L_{st}, C_t, C_{st}, C_{Hst}, C_{Fst}, D_{Cst}, M_{st}, $M_{s'st}$,$M_{Hs'st}$, $M_{Fs'st}$, $D_{Ms'st}$, X_{st}, Y_{st}, $\Pi_t\}$ that maximize utility for the consumer, maximize profits for firms, and clear markets for goods and labor. A brief presentation of the equilibrium conditions can be found in Appendix 1.

3.2 Import Competition

Before moving to the results, here I present how the variable markups interacting with imports yield the pro-competitive and anti-competitive mechanism, following notes by Arkolakis and Morlacco [2017]. I also argue how the anti-competitive effect compounds in the multi-sector structure.

3.2.1 Pro-Competitive Effect

The pro-competitive effect can be thought of as the optimal response of imperfectly competing firms to an increase of imports. Essentially, when imports enter a specific market they reduce its aggregate prices, to the benefit of consumers and detriment of domestic firms. This price reduction can be decomposed in two channels. The more straightforward is plain substitution of sales, foreign production replacing domestic supply at a lower price. But incumbent firms also react to the entry of imports. Facing tougher competition, and assuming they have positive margins, domestic suppliers can lower their own prices to avoid losing too many sales. In this sense, imports are not only beneficial through a decrease in prices, but also because the increase in competition lowers domestic markup distortions.

Kimball preferences delivers the pro-competitive effect of trade as follows. Optimal markups for firm i will vary with the price elasticity of demand, in turn determined by the ratio between the firm's price P_{Hst} and the aggregate price level in the market it serves, either P_{Cst} in consumption goods or $P_{Ms'st}$ in inputs.

In the symmetric equilibrium, optimal pricing gives

$$\mu_{Hst} = \frac{\epsilon_{Hst}}{\epsilon_{Hst} - 1} \tag{52}$$

where the elasticity of demand for goods of sector s is a weighted average of the elasticities in each market

$$\varepsilon_{Hst} = \varepsilon^{C}_{Hst}\frac{C_{Hist}}{C_{Hist} + \sum_{s'} M_{Hss't}} + \sum_{s'} \varepsilon^{M}_{Hss't}\frac{M_{Hss't}}{C_{Hist} + \sum_{s'} M_{Hss't}} \tag{53}$$

and the elasticity of demand in each market is determined by

$$\varepsilon^{C}_{Hst} = \sigma_s \left(1 + \epsilon_s \ln\left(\frac{\sigma_s}{\sigma_s - 1}\right) - \epsilon_s \ln\left(D_{Cst}\frac{P_{Hst}}{P_{Cst}}\right)\right)^{-1} \tag{54}$$

$$\varepsilon^{M}_{Hss't} = \sigma_s \left(1 + \epsilon_s \ln\left(\frac{\sigma_s}{\sigma_s - 1}\right) - \epsilon_s \ln\left(D_{Mss't}\frac{P_{Hst}}{P_{Mss't}}\right)\right)^{-1} \tag{55}$$

this delivers the nature of variable markups. Setting demand indices D_{Cst} and $D_{Mss't}$ aside, and even though domestic firms are symmetric, markups are variable insofar the relation between domestic prices and aggregate prices $\frac{P_{Hst}}{P_{Cst}}$ and $\frac{P_{Hs't}}{P_{Ms'st}}$ is also affected by foreign prices P_{CFst} and $P_{MFs'st}$ through the respective denominators. For instance, when there is a surge in imports of final goods, in this model P_{CFst} decreases, driving consumer prices P_{Cst} downward. The domestic firm in turn will lower its markups μ_{Hst} as its elasticity of demand ε^{C}_{Hst} increases.

3.2.2 Anti-Competitive Effect

The anti-competitive effect is also just the optimal response of imperfectly competing firms to an increase of imports, but now with respect to the import of inputs.

For example, when imports lower prices in one market, downstream firms buy their inputs for less, lowering their costs of production. With imperfect competition, firms will not fully transmit their cost reduction to their costumers, increasing their markups while reducing prices.

The anti-competitive effect operates through Kimball preferences as they also deliver variable cost pass-through. The super-elasticity of demand, that is the elasticity of demand elasticity, is defined here (for consumption goods) as

$$\Gamma_{Hst}^{C} = \frac{\epsilon_s}{\left(\sigma_s - 1 - \epsilon_s \ln\left(\frac{\sigma_s - 1}{\sigma_s}\right) + \epsilon_s \ln\left(D_{Cst}\frac{P_{Hst}}{P_{Cst}}\right)\right)} \quad (56)$$

which makes the firm's cost pass-through Φ_{Hst}^{C}, the price elasticity to a change in costs

$$\Phi_{Hst}^{C} = \frac{1}{1 + \Gamma_{Hst}^{C}} \quad (57)$$

and analog for inputs.

In the CES case, the elasticities are fixed so the super-elasticity $\Gamma_{Ht}^{C} = 0$ and the cost pass-through $\Phi_{Ht}^{C} = 1$. But in the Kimball case, both markups and pass-through change with the price ratio. Note also the imperfect pass-through operates both through foreign inputs $P_{MFs't}M_{Fs'st}$, and domestic inputs $P_{Hs't}M_{Hs'st}$ supplied by other sectors.

To illustrate how incomplete cost pass-through matters, consider the response of a domestic firm when the foreign price of an input changes. Assume the price of a foreign input drops, and the resulting re-optimization yields a drop in marginal costs of 10%. In the CES case, demand elasticities are fixed and pass-through is complete, so prices drop by the same 10%. However, with Kimball preferences, the same 10% creates a smaller price drop, say 5%, as the demand elasticity faced by the domestic firm is reduced. At the same time, the reduction of demand elasticity means markups adjust up. The anti-competitive effect is thus a consequence of the cost-price pass-through Φ^{C}_{Ht} being less than one.

3.2.3 Import Competition with Input-Output

There are two key differences of using variable markups in one sector models, multi-sector models, and interdependent multi-sector models. First, the anti-competitive effect manifests most clearly through the vertical interdependence described by the Input-Output structure of production. This vertical relation means shocks in upstream markets have consequences to productive units downstream. With multiple domestic sectors supplying each other, the anti-competitive effect operates through both imported $P_{MFs'st}M_{Fs'st}$, and domestic inputs $P_{Hs't}M_{Hs'st}$. Second, with sectors supplying sectors, in turn supplying other sectors, there are potentially multiple steps for the cost-price pass-through to operate.

To illustrate, take the following example. Assume two firms in a linear supply chain structure. The first firm produces Y_1 by picking up a raw resource at cost mc_1, and sells it at price $p_1 = \mu_1 mc_1$. If for some reason the cost of picking up the raw resource mc_1 changes, the elasticity of consumer prices p_1 with respect to initial cost mc_1 will be

$$\frac{\partial \ln p_1}{\partial \ln mc_1} = \frac{\partial \ln \mu_1}{\partial \ln mc_1} + 1 \tag{58}$$

With CES technology, markups are fixed, so the markup elasticity to costs is $\frac{\partial \ln(\mu_1)}{\partial \ln mc_1} = 0$, and we have full cost pass-through $\frac{\partial \ln p_1}{\partial \ln mc_1} = 1$. But with Kimball technology, incomplete pass-through means markups move in the opposite direction of costs $\frac{\partial \ln(\mu_1)}{\partial \ln mc_1} < 0$, as prices affect the elasticity of demand.[3]

The second firm buys the good, pays for no other input so $p_1 = mc_2$, charges markup μ_2, and sells it forward at p_2, with analog cost pass-through

$$\frac{\partial \ln p_2}{\partial \ln mc_2} = \frac{\partial \ln \mu_2}{\partial \ln mc_2} + 1 \tag{59}$$

The final consumption price is the product of the initial price and the subsequent markups

$$p_2 = \mu_2 p_1 = \mu_2 \mu_1 mc_1 \tag{60}$$

and again, the price elasticity to the initial cost is

$$\frac{\partial \ln p_2}{\partial \ln mc_1} = \frac{\ln \mu_2}{\ln mc_1} + \frac{\ln \mu_1}{\ln mc_1} + 1 \tag{61}$$

how do we know this elasticity $\frac{\ln p_2}{\ln mc_1} > 0$ is positive when we are adding multiple steps of negative elasticities $\frac{\ln \mu_2}{\ln mc_1} < 0$ and $\frac{\ln \mu_1}{\ln mc_1} < 0$? Using the chain rule and recognizing $mc_2 = p_1$ we have

$$\frac{\partial \ln p_2}{\partial \ln mc_1} = \underbrace{\frac{\partial \ln \mu_2}{\partial \ln mc_2}}_{<0} \underbrace{\left(\frac{\partial \ln \mu_1}{\partial \ln mc_1} + 1\right)}_{\in[0,1]} + 1 \tag{62}$$

so a drop in upstream costs will never induce a downstream price increase, or

[3] Also note the markup elasticity to costs would be at most 1 with inelastic demand and infinite markups, and the price cost elasticity would be at most null.

vice-versa, no matter how many steps are in the chain.

4 Results

In this section I present the results of estimating the model. Before any results, I present the calibration strategy to set the parameters, using the year 2007 as baseline. With the parameters set, I will conduct two sets of exercises. First, to present the behavior of the model I will exogenously shock foreign marginal costs, once for consumption and once for inputs. Second, I will use my baseline calibration to retrieve the marginal costs matching data on domestic expenditure shares, and use them to compare the change in US welfare attributable to the increase in imports between 1997 and 2007 under different pass-through assumptions.

4.1 Calibration

The multi-sector structure means some parameters are unique, others are vectors where each value corresponds to a sector, and others are matrices where the elements correspond to sector-by-sector parameters. In this sense, the dimension of the calibration increases depending on the number of sectors S. As a starting point, I set the number of sectors $S = 2$. There are 14 groups of parameters to be calibrated and 6 exogenous groups of variables, comprising $5 + 11S + 4S^2$ parameters and variable values, as listed below.

4.1.1 External Calibration

The first 8 sets of parameters are calibrated externally following preceding literature, and most will remain fixed throughout. The external calibration is summarized in Table 1.

Table 1: External Calibration

Definition	Value	Source
Decreasing returns to consumption	$\rho = 1$	Log-utility
CES across sectors s Consumption	$\vartheta = 1$	Cobb-Douglas
CES across sectors s' Inputs	$\kappa_s = 1$	Cobb-Douglas
Kimball coefficient (levels)	$\sigma_s = 3$	Comin and Johnson [2022]
Kimball coefficient (super-elasticity)	$\epsilon_s = 2$	Comin and Johnson [2022]
Inverse of the Frisch elasticity	$\psi = 2$	Chetty et al. [2011]
CES across sources Exports	$\epsilon_X = 3$	$\mu_X = \frac{\epsilon_X}{\epsilon_X - 1} = 1.5$
CES across varieties Exports	$\eta_{Xs} = 3$	Feenstra et al. [2018]

I start discussing the parameters σ_s and ϵ_s of the Kimball aggregators, which determine the dynamic of markups through two pairs of objects. As evidenced in equations $(52 - 57)$, the pair (σ_s, ϵ_s) determines markups μ_{Hst}, the elasticity of demand ε_{Hst}, the super-elasticity of demand Γ_{Hst}, and price-cost pass-through Φ_{Hst}. In a symmetric steady state, that is when $\frac{P_{Hs0}}{P_{Cs0}} = 1$, the demand index simplifies to $D_{Cs0} = \frac{\sigma_s - 1}{\sigma_s}$. Then the symmetric elasticity of demand becomes fixed at $\epsilon^C_{Hs0} = \sigma_s$, the super-elasticity is $\Gamma^C_{Hs0} = \frac{\epsilon_s}{\sigma_s - 1}$, and the cost pass-through is $\Phi^C_{Hst} = \frac{\sigma_s - 1}{\sigma_s - 1 + \epsilon_s}$. To be clear, this symmetry only occurs when all domestic and all foreign firms charge the same prices.

For my baseline I set the same values for the pair across sectors $\{\sigma = 3, \epsilon = 2\}$ following Comin and Johnson [2022]. These values give markups of $\mu^C_{Hst} = 1.5$, and

Home pass-through of $\Phi_{Hst} = 0.5$. I also try using $\{\sigma = 2, \epsilon = 1\}$ as in Gopinath et al. [2020], with similar results (not reported). Other values used in the literature include $\{\sigma = 5, \epsilon = 4\}$ in Gopinath and Itskhoki [2010], $\{\sigma = 5, \epsilon = 10\}$ in Smets and Wouters [2007], and $\{\sigma = 5, \epsilon = 33\}$ in Eichenbaum and Fisher [2007]. A deeper discussion on the implications of these parameters can be found in Klenow and Willis [2016]. While discussing these parameters, note that when $\epsilon \to 0$ the Kimball aggregator simplifies to $\Upsilon(x) = x^{\frac{\sigma-1}{\sigma}}$ making markups fixed in all cases. This special case of the aggregator is equivalent to a nested CES structure with the same coefficient of substitution for each level.

In this line, I set the CES substitution coefficients for exports to $\eta_{Xs} = \epsilon_{Xs} = 3$, making markups of exports $\mu_{Xs} = 1.5$, the same as the (symmetric) domestic markups. Equating the two is consistent with the discussion on elasticities in Feenstra et al. [2018]. For labor, I set $\psi = 2$ to match a Frisch elasticity of $\frac{1}{\psi} = 0.5$, as discussed in Chetty et al. [2011]. Furthermore, I set $\rho = 1$ producing log utility in consumption, also standard in quasi-static models, where ρ is the rate at the which the marginal utility of consumption decreases. This is also in the context of no inter-temporal decisions, nor any risk. And finally, I set substitution parameters across sectors ϑ and κ_s to 1, which makes sector composition follow a Cobb-Douglas structure. I keep the externally calibrated coefficients symmetric across sectors, so for example $\sigma_s = \sigma \, \forall s$.

4.1.2 Internal Calibration

The second batch for calibration consists of 6 sets of parameters and 2 sets of values, which are determined by matching 6 sets of moments in data at baseline, and making 2 sets of normalization. The moments from data are: the domestic expenditure shares for consumption Λ^C_{s0} and for inputs $\Lambda^M_{s's0}$, the weight of inputs in total costs MS_{s0}, the weight of individual inputs in total costs $MS_{s's0}$, the sector shares of consumption CS_{s0}, and nominal GDP_{s0}. I will also assume no trade deficit $T_0 = 0$. These data moments pin down the parameters and values $(\nu_s, \xi_{s's}, \zeta_s, \alpha_s, \alpha_{s's}, Z_{s0}, T_{s0})$. When computing equilibrium off baseline, these parameters are held fix at the baseline numbers. All data moments come from the Input-Output construction described below. The last two parameters, ς and C^*_s are set by normalizing domestic prices $P_{Ht} = W_t = 1$.

Table 2: Internal Calibration

Definition	Value	Target
Home bias Consumption	$\nu_s = \begin{pmatrix} 0.66 \\ 0.99 \end{pmatrix}$	Λ^C_{s0}
Home bias Inputs	$\xi_{s's} = \begin{pmatrix} 0.78 & 0.79 \\ 0.83 & 0.98 \end{pmatrix}$	$\Lambda^M_{s's0}$
Home bias Consumption sectors	$\zeta_s = \begin{pmatrix} 0.16 \\ 0.84 \end{pmatrix}$	CS_0
Inputs in Production	$\alpha_s = \begin{pmatrix} 0.79 \\ 0.50 \end{pmatrix}$	MS_{s0}
Inputs in Production from sector s'	$\alpha_{s's} = \begin{pmatrix} 0.43 & 0.10 \\ 0.36 & 0.40 \end{pmatrix}$	$MS_{s's0}$
Domestic Productivity	$Z_{s0} = \begin{pmatrix} 3.45 \\ 4.00 \end{pmatrix}$	GDP_{s0}
Labor dis-utility scale parameter	$\varsigma = 0.01$	$W_0 = 1$
Foreign Consumption	$C^*_{s0} = \begin{pmatrix} 1 \\ 1 \end{pmatrix}$	$P_{Hs0} = 1$

I set my baseline in 2007 instead of 1997 for practical reasons. In particular, the home bias parameters for 1997 ν_s and $\xi_{s's}$ were sometimes very close to one, showing how closed the non-manufacturing sector was in 1997. This strong Home bias diminished precision, affecting results. Also, I am fixing nominal Foreign Transfers T_0 to prevent real transfers of resources.

4.1.3 Data for calibration

The internally calibrated parameters are set by matching moments in the model with moments in US data. To retrieve these analog moments in data, I construct an adjusted Input-Output table for the US working with the national accounts from the Bureau of Economic Activity (BEA). More specifically, I combine the summarized tables (73 sectors) from 1997 to 2016 on Make, Use, and Import Matrices after re-definitions, transforming the matrices in two dimensions.

First, for simplicity I collapse the tables from 73 sectors to 2 sectors, manufacturing and non-manufacturing. The manufacturing sector are defined as all NAICS2 sectors of the manufacturing family, with the rest set to non-manufacturing. This division responds to the characteristics of the 1997-2007 period, in particular an important trade liberalization with China, which characterizes the period. The China Shock had a clear differential effect on manufacturing, so I single manufacturing from the rest of the economy.

Second, the adjustments respond to limitations of BEA data. For one, imports are not separately taken into account in the Make and Use tables, making it difficult to track down which inputs are domestic and which are imported. This is necessary to retrieve the domestic expenditure shares. Second, the Make and Use tables are not industry by industry tables, which complicates the analysis of upstream and downstream effects. I combine the three tables to make a unified

Input-Output matrix, following the derivation procedure for the total requirement tables, mixed with the definition of the imports tables.

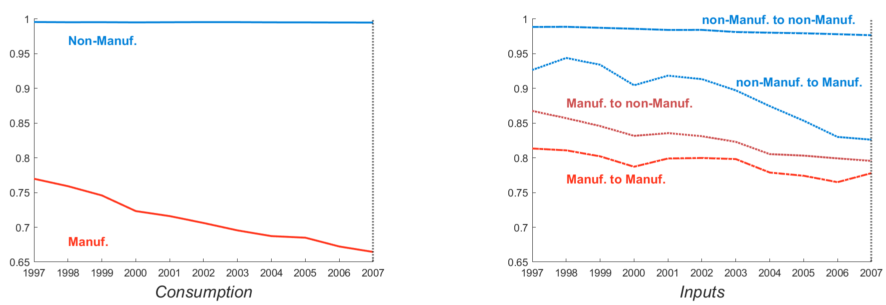
The end product is a matrix matching industries to industries that also tracks down domestic and foreign production separately. This adjusted Input-Output tables from 1997 to 2016 now comprises many variables present in the model, from the which I construct the data moments used in the internal calibration, in particular:

$$\begin{aligned}
\overline{GDP}_{st} &= \overline{P_{Hst}C_{Hst}} + \sum_{s'} \overline{P_{Hs't}M_{Hs'st}} + \overline{P_{Xs}X_s} - \overline{P_{Mst}M_{st}} && (63)\\
\overline{CS}_{st} &= \frac{\overline{P_{Cst}C_{st}}}{\overline{P_{Ct}C_t}} && (64)\\
\overline{MS}_{st} &= \frac{\overline{P_{Mst}M_{st}}}{\overline{P_{Mst}M_{st}} + \overline{W_t L_{st}}} && (65)\\
\overline{MS}_{s'st} &= \frac{\overline{P_{Ms'st}M_{s'st}}}{\overline{P_{Mst}M_{st}} + \overline{W_t L_{st}}} && (66)\\
\overline{\Lambda}^C_{st} &= \frac{\overline{P_{Hst}C_{Hst}}}{\overline{P_{Cst}C_{st}}} && (67)\\
\overline{\Lambda}^M_{s'st} &= \frac{\overline{P_{MHs'st}M_{Hs'st}}}{\overline{P_{Ms'st}M_{s'st}}} && (68)
\end{aligned}$$

where $\overline{GDP}_{st}$ is the gross domestic product of sector s. $\overline{CS}_{st}$ is the share of consumption from sector s in aggregate consumption, and $\overline{MS}_{st}$ is the share of all intermediate inputs in costs for sector s, while $\overline{MS}_{s'st}$ is the share of intermediate inputs from sector s' in costs for sector s. $\overline{\Lambda}^C_{st}$ is the domestic expenditure share of consumption in sector s, and $\overline{\Lambda}^M_{s'st}$ is the domestic expenditure share of inputs from sector s' bough by sector s .The line over the variables denotes data or transformations of data, noting the Input-Output tables are set in millions of dollars.

The domestic expenditure shares $\overline{\Lambda}_{st}^{C}$ and $\overline{\Lambda}_{s'st}^{M}$ are of particular importance in the literature, as Arkolakis et al. [2012] and Arkolakis et al. [2019] propose them as be sufficient statistics for the increase in welfare for a large class of models. Therefore I plot both the domestic expenditure share of consumption and inputs in Figure 1 below. It is clear from the figure that between 1997 and 2007 foreign manufacturing has gained ground on domestic expenditure, both in consumption and inputs, as shown by the lines in red. Foreign exposure is a bit different for non-manufacturing sectors. Consumption of non-manufacturing goods remains almost entirely domestic, while non-manufacturing domestic input use by the own non-manufacturing sector drops only slightly. The remaining case does show a reduction, that is non-manufacturing inputs used to produce manufacturing goods.

Figure 1: Domestic Sourcing Shares



Input use is relevant to interpret the figure, as it is different across the two sector groups. These are evidenced in matrix A^{2007} below, the direct requirement matrix. Here each element represents the weight of inputs from each row sector in total costs of the column sector. For example, 0.43 is the weight of manufacturing inputs in manufacturing costs. The sum of each column is total input intensity, 0.79 for manufacturing and 0.50 for non-manufacturing, thus the width of the cost channel. The off-diagonal elements suggest the anti-competitive effects would be more potent from non-manufacturing to manufacturing $A^{2007}_{(2,1)} = 0.36$ than from manufacturing to non-manufacturing $A^{1997}_{(1,2)} = 0.10$.

$$A^{1997} = \begin{pmatrix} 0.43 & 0.10 \\ 0.36 & 0.40 \end{pmatrix} \tag{69}$$

4.2 Results - Exogenous Shocks

The first step is to compute the equilibrium for US data in 2007 and use it as benchmark. From this benchmark, and keeping the remaining parameters fixed, I will introduce one of two reductions in Foreign marginal costs. To avoid repetition as much as possible, I will sometimes refer to manufacturing as "sector 1", and non-manufacturing as "sector 2".

First, to mimic import competition in manufacturing sales, I impute a 10% reduction in the marginal cost of manufacturing consumption goods, MC^*_{C1}. With 50% pass-through, this translates to foreign prices decreasing 5%. I am shocking foreign marginal costs instead of foreign prices because foreign prices are an equilibrium object, subject to its own variable markups. I report the corresponding results on the first columns of tables $(3 - 5)$. Second, now inducing import competition on inputs, I lower marginal costs on foreign manufacturing inputs used by the domestic non-manufacturing sector, MC^*_{M12}. Its corresponding results are reported in the second columns of tables $(3 - 5)$.

With these new foreign marginal costs, I recompute the equilibrium of the model and compare it to the benchmark. I present these results as percent changes from the benchmark. To summarize, I will present only changes for markups (by market and sector), (sector) output and factors of production, and aggregate variables.

The first column of Table 3 shows how markups change as a result of the lower foreign marginal costs. The lower costs at the Foreign economy are imperfectly passed-through to import prices, which compete with domestic production. This results in a -2.4% drop in markups of manufacturing consumption goods, and adds up to -0.7% for total manufacturing markups. In addition, the lower manufacturing prices also lower domestic costs and increase domestic markups. This is true both for sector 1's and sector 2's use of manufacturing inputs, leading to a 0.7% increase in markups. Here we see the anti-competitive effect at play, as some markups increase due to incomplete pass-through. The results also highlights the fact that the pro-competitive and anti-competitive effects both operate as a result of a single shock.

Table 3: Results - Markups by Sector

		10 % drop	
		MC^*_{C1}	MC^*_{M12}
Markups M	μ_{H1}	-0.7	-0.3
Markups NM	μ_{H2}	0.0	0.0
Markups Consumption M	μ^C_{H1}	-2.4	0.4
Markups Consumption NM	μ^C_{H2}	0.0	0.0
Markups Inputs M to M	μ^M_{H11}	0.7	0.3
Markups Inputs M to NM	μ^M_{H12}	0.7	-1.9
Markups Inputs NM to M	μ^M_{H21}	0.1	0.0
Markups Inputs NM to NM	μ^M_{H21}	0.0	0.0

percent change from 1997

The second column of Table 3 shows the effect on markups of decreasing foreign marginal costs of manufacturing goods selling to sector 2, producing non-manufacturing. Similarly to the previous case, the sharpest impact is on domestic markups of competing input providers, "Inputs NM to M", which decreases -1.9%. But here there are also multiple markup-increasing effects. For example, markups for manufacturing consumption go up 0.4%.

Table 3 shows how different drops in foreign costs, which translate to lower foreign prices, will impact domestic markups differently. Depending on how they relate to the exposed sector, markups will decrease when competing with imports, or increase when using them as inputs.

Now turning towards supply in each sector, Table 4 presents how production and factors of production change in each sector. Starting with the first column, production in the exposed sector goes down -0.8% after the drop in foreign marginal costs. At the same time, production in non-manufacturing increases as a combination of lower markups in manufacturing and reallocation of labor.

Table 4: Results - Reallocation by Sector

		10 % drop	
		MC^*_{C1}	MC^*_{M12}
Labor M	L_1	-0.7	-0.3
Inputs M	M_1	-0.8	-0.1
Home Output M	Y_1	-0.8	-0.1
Labor NM	L_2	0.1	0.1
Inputs NM	M_2	0.1	0.8
Home Output NM	Y_2	0.1	0.4

percent change from 1997

The second column of Table 4 is also informative. Here inputs bought by the non-manufacturing sector will lower their price, creating both an increase in production due to better marginal costs, but also a reallocation of factors towards inputs. The net effect is production increasing 0.4%.

Finally, table 5 gives the aggregate results of each shock. Comparing results across the first line, the shock to consumption in sector 1 creates more welfare than shocking the manufacturing inputs used in sector 2. It also creates more jobs, and induces higher real wages. However, moving to the second half of the table, the shock on consumption seems to improve the real wage bill by more, whereas the shock to inputs creates a larger gain in real profits. This is not surprising given the shock in the first column lowers markups by more, whereas the shock in the second column has larger output.

Table 5: Results - Aggregate

		10 % drop	
		MC^*_{C1}	MC^*_{M12}
Consumption	C	0.31	0.26
Labor	L	0.07	0.03
Real Wages	$\frac{W}{P_C}$	0.45	0.31
Real GDP	$\frac{WL+\Pi}{P_C}$	0.31	0.26
Real Wage Bill	$\frac{WL}{P_C}$	0.52	0.34
Real Profits	$\frac{\Pi}{P_C}$	0.12	0.18

percent change from 1997

This exercise illustrates how different individual shocks go into the equilibrium, affecting markups, production, and welfare. However, these do not match any real-world change or moment in data. In the next exercise I will do just that, retrieving the foreign marginal costs from data, and feeding them through various specifications.

4.3 Results - Model Inversion

The objective of this exercise is to capture how changes in import competition affect welfare in my model. The first step is calibrating to the benchmark in year 2007. I will capture import competition using data on the domestic expenditure shares in consumption and inputs for each sector Λ^C_{st} and $\Lambda^M_{s'st}$. Then I will compare results from this benchmark to other equilibria.

To be clear, I will take the ratio between my benchmark 2007 equilibrium in the denominator, and in the numerator I will have 1997 equilibria under three different specifications. Comparing these ratios is appropriate across specification because I assume a symmetric baseline calibration, meaning the 2007 benchmark will have the same equilibrium under the three specifications.

I find the first off-benchmark equilibrium by internally calibrating marginal costs to 1997 data, taking the parameters calibrated to 2007 as given. This case I label "Base Pass-Through", as it uses the same 50% pass-through as in the benchmark calibration. In addition to computing the impact of import competition, this estimation also retrieves the $S + S^2$ foreign marginal costs that match the entry of foreign goods $\{MC_{CFst}, MC_{MFs'st}\}$. I call those retrieved foreign marginal costs the "inverted shocks".

The second off-benchmark equilibrium consists on feeding those inverted shock through the model, with one variation. The calibration for this exercise assumes most of the same parameters from the "Base Pass-Through" case, with the exception of the Kimball super-elasticity parameter which I now set to $\epsilon_s = \frac{1}{10}$. This alternate calibration keeps symmetric average markups the same in the benchmark, but increases cost pass-through to 95%. I label this the "High Pass-Through" case, and delivers the effect of the same marginal cost change with less responsive markups.

Finally, I compute a third off-benchmark equilibrium, now feeding the inverted shocks in an analog model, replacing Kimball preferences and technology of aggregation with the more common CES preferences and technology. As mentioned in the calibration section, this is a limiting case of the High Pass-Through case, where now $\epsilon \to 0$, so I label it the "Full Pass-Through" case.

The results are presented through a selection of variables in tables $5-8$. These results will be percent changes from 1997, in analog way to the previous exercises. Results in the first column correspond to the Base Pass-Through equilibrium, where I compare equilibria in 1997 and 2007 with 50% pass-through. In the second column I present results for the second off-baseline case, feeding the inverted shocks in the same model but now with 95% pass-through. And finally results in the third column present results using 100% pass-through, the CES version of the model. Together, these exercises allows me to asses the role of variable markups, as ϵ_s rules over how variable markups are. This super-elasticity of demand is also directly related to pass-through, as discussed before.

Table 6 below presents markups in each exercise. Starting with the Base case, there is a generalized reduction in markups as as the elasticity of demand changes in all markets. This is a net effect, as the countervailing forces displayed in the Results for Exogenous Shocks are still operative. Markups in consumption manufacturing decrease the most, with -7.6% lower than 1997. In the High Pass-through case markups reasonably react by less, with the larger effect being a -0.5% in consumption manufacturing. Note the Full Pass-through case corresponds to fixed markups, so there is no change in markups with respect to 1997.

Table 6: Results - Markups by Sector

		Pass-Through		
		Base	High	Full
Markups M	μ_{H1}	-5.5	-0.4	–
Markups NM	μ_{H2}	-0.4	-0.0	–
Markups Consumption M	μ^C_{H1}	-7.6	-0.5	–
Markups Consumption NM	μ^C_{H2}	-0.0	-0.0	–
Markups Inputs M to M	μ^M_{H11}	-2.2	-0.2	–
Markups Inputs M to NM	μ^M_{H12}	-5.0	-0.3	–
Markups Inputs NM to M	μ^M_{H21}	-4.7	-0.3	–
Markups Inputs NM to NM	μ^M_{H21}	-0.5	-0.0	–

percent change from 1997

The productive reallocation from differential exposures to import competition are better appreciated in Table 7. I separate each sector as before, and order them from factors of production L_j, M_j to output Y_j. In the Base Pass-Through case we see both sectors grow with respect to 1997, with visible reallocation of factors from labor towards intermediate inputs. This is consistent with both the decrease in markups and the decrease in marginal costs of inputs stemming from import competition and is gains through the cost channel.

Table 7: Results - Reallocation by Sector

		Pass-Through		
		Base	High	Full
Labor M	L_1	-2.8	-12.0	-12.6
Inputs M	M_1	11.6	-1.5	-2.3
Home Output M	Y_1	8.4	-3.8	-4.5
Labor NM	L_2	1.0	1.4	1.4
Inputs NM	M_2	9.1	7.4	7.3
Home Output NM	Y_2	5.0	4.4	4.3

percent change from 1997

The High and Full pass-through cases present a similar reallocation, with manufacturing output decreasing -3.8% and -4.5%. The reduction is less marked on inputs at -1.5% and -2.3%, and instead a sharp destruction of labor -12.0% and -12.6%. The effects in non-manufacturing are a moderated version of the Base case, with slightly more growth of labor and slightly less growth in the use of intermediate inputs.

This highlights the role of variable markups as a cushion for domestic production. The more variable markups are, the better domestic production fares. In the opposite direction, markups provide less of a cushion the higher the pass-through is.

Table 7 also shows a reduction in manufacturing labor across all specifications. This is fueled by both changes in factor demand given the lower production, and changes in favor of the more affordable input basket. This is also consistent with the decline in manufacturing labor found in empirical literature of this period.

Before aggregating results, it is worth keeping track of sector sizes. Calibrating to the US economy in 2007, manufacturing counts for 19% of consumption and 14% of GDP. In that context, Table 8 shows consumption grows 6.15% in the Base Pass-through case, which I interpret as the gains from trade in this static model, net positive as expected. Labor grows 0.71% compared to 1997, and real wages increase 7.66%. In sum, real consumption, labor, and wages increase. Thinking on how consumption is financed, real GDP also increases by 6.15%. By real GDP I mean GDP over consumption prices. The wage bill grows by 8.43%, more than profits that grow 4.13%

Table 8: Results - Aggregate

		Pass-Through		
		Base	High	Full
Consumption	C	6.15	5.17	5.14
Labor	L	0.71	0.27	0.24
Real Wages	$\frac{W}{P_C}$	7.66	5.75	5.65
Real GDP	$\frac{WL+\Pi}{P_C}$	6.15	5.17	5.14
Real Wage Bill	$\frac{WL}{P_C}$	8.43	6.04	5.91
Real Profits	$\frac{\Pi}{P_C}$	4.13	4.40	4.46

percent change from 1997

Here the cases with higher cost pass-through have lower growth of real consumption 5.17% and 5.14%. Also more moderate changes occur in labor for each case 0.27% and 0.24%, and in real wages 5.75% and 5.65%, resulting in lower growth of the wage bill 6.04% and 5.91%. Somewhat surprisingly, real profits grow by more than in the Base case. This implies both the growth and size of non-manufacturing, combined with the relatively fixed markups, more than compensate the decrease in manufacturing production.

All in all, the three comparisons evidence the role played by variable markups. The more variable markups are, that is the lower their pass-through, the higher the increase in real consumption. As for magnitudes, in my calibration the base case increases consumption by 1% more than the CES, which can be interpreted as reaping 20% more gains from trade.

The mechanism along the structure is also important. The pro-competitive and anti-competitive effects at the same time cushion shocks received by domestic production, while helping transmission across sectors through cost. The input-output structure provides reallocation within and across sectors, taking into account cost channels of different widths in the structure of production. And the general equilibrium framework allows for changes in labor supply and wages, as the economy faces more import competition.

5 Conclusion

In this paper I study how including pro-competitive and anti-competitive effects can change the gains from trade, in a multi-sector small open economy model with trade and an Input-Output structure. Estimating this model to the US in 1997 and 2007, I find that the gains from trade increase by 20% when including variable markups. My computations also show how the internal reallocation of demand and variable demand elasticity work through the Input-Output structure, and how incomplete pass-through plays a consequential role.

This paper is a first step in incorporating richer competitive effects in trade models, and suffers from some immediate shortcomings. First, for simplicity, the structure chosen is just enough to include domestic anti-competitive effects. However, there is room for improvement, both by expanding the number of sectors as well as matching data on sector markups. Even more, increasing the number of sectors would have qualitative implications, as it increases the importance of imperfect cost pass-through and double marginalization.

A second immediate limitation is laid bare by the small labor destruction in manufacturing. There is consensus in the literature is that the China Shock, an important flow of imports in this period, destroyed labor in manufacturing, but in my preferred specification manufacturing labor decreases by less than 3%. This might be due to the parameters used in the calibration, in particular fixed sector productivity, but also to the nature of the firm in this model. My model has no entry cost, nor fixed cost of operating, so a drop in profitability is just a drop in transfers to the owners of the firm, and the size of each sector remains the same. In a similar sense, the lack of investment means there is no resource reallocation from less profitable firms to more profitable firms. Enriching the supply side of the firms could lift this limitation. This second limitation might also speaks to the nature of the decline in manufacturing labor linked to the number of firms and exit.

Taking into account firm heterogeneity within sector would be an informative future extensions, as heterogeneity in competition across markets adds another dimension of the competitive mechanism. Something similar to the analysis made by Edmond et al. [2018] would help me complement how firm heterogeneity affect the gains from trade, in a setting not too far removed from mine. If both the pro-competitive effect and cost pass-through affect welfare, gains from trade will depend on what markets get liberalized, how competitive those markets are, and how the production network is organized. In general, foreign entry in markets that are more competitive and/or closer to the consumer should decrease prices of final goods by more, while entry in less competitive markets and/or farther from the consumer will increase successive markups by more.

Finally, a more refined version of this model could help bridge the approaches taken by Arkolakis et al. [2019] and Baqaee and Farhi [2023]. Here competitive effects are welfare-improving as in Arkolakis et al. [2019], but departing from fixed markups is not enough, as the vertical relation between sectors is instrumental to get anti-competitive effects. The converse argument can be made of the welfare analysis in Baqaee and Farhi [2023]. If flexible markups compound the effects of trade liberalization along the Input-Output structure, the net welfare effects would differ from using fixed wedges.

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Appendix 1 - Equilibrium Summary

Given the values for $\{MC_{CFst},\ MC_{MFs'st},\ Z_{st},\ P^{*}_{Cst},\ C^{*}_{st}\}$ and parameters $\{\rho,\ \psi,\ \vartheta,\ \varsigma,\ \epsilon_s,\ \sigma_s,\ \eta_{Xs},\ \epsilon_{Xs},\ \zeta_s,\ \kappa_s,\ \nu_s,\ \alpha_s,\ \xi_{s',s},\ \alpha_{s's}\}$, the equilibrium conditions pin prices $\{P_{Hst},\ MC_{st},\ P_{Ct},\ P_{Cst},\ P_{Mst},\ P_{Ms'st},\ P_{Xst},\ W_t,\ P_{CFst},\ P_{MFs'st}\ \}$ and allocations $\{L_t,\ L_{st},\ C_t,\ C_{st},\ C_{Hst},\ C_{Fst},\ D_{Cst},\ M_{st},\ M_{s'st},\ M_{Hs'st},\ M_{Fs'st},\ D_{Ms'st},\ X_{st},\ Y_{st},\ \Pi_t\}$ as determined by the following system of equations

$$C_t^{-\rho}\frac{W_t}{P_{Ct}} = \varsigma L_t^{\psi} \tag{70}$$

$$C_{st} = \zeta_s\left(\frac{P_{Cst}}{P_{Ct}}\right)^{-\vartheta} C_t \tag{71}$$

$$C_{Hst} = \nu_s \Psi\left(D_{Cst}\frac{P_{Hst}}{P_{Cst}}\right) C_{st} \tag{72}$$

$$C_{Fst} = (1-\nu_s)\,\Psi\left(D_{Ct}\frac{P_{CFst}}{P_{Cst}}\right) C_{st} \tag{73}$$

$$1 = \nu_s \Upsilon\left(\frac{C_{Hst}}{\nu_s C_{st}}\right) + (1-\nu_s)\,\Upsilon\left(\frac{C_{Fst}}{(1-\nu_s)\,C_{st}}\right) \tag{74}$$

$$P_{Cst} = P_{Hst}\frac{C_{Hst}}{C_{st}} + P_{CFst}\frac{C_{Fst}}{C_{st}} \tag{75}$$

$$P_{Ct} = \left(\sum_s \zeta_s P_{Cst}^{1-\vartheta}\right)^{\frac{1}{1-\vartheta}} \tag{76}$$

$$P_{Ct}C_t = W_t L_t + \Pi_t + T_t \tag{77}$$

$$W_t L_{st} = (1-\alpha_s)\,Y_{st} MC_{st} \tag{78}$$

$$P_{Mst}M_{st} = \alpha_s Y_{st} MC_{st} \tag{79}$$

$$MC_{st} = Z_{st}^{-1}\,(1-\alpha_s)^{-(1-\alpha_x)}\,\alpha_s^{-\alpha_s} W_t^{(1-\alpha_s)} P_{Mst}^{\alpha_s} \tag{80}$$

$$P_{Ht} = \frac{\epsilon_{Hst}}{\epsilon_{Hst}-1} MC_t \tag{81}$$

$$M_{s'st} = M_{st}\left(\frac{\alpha_{s's}}{\alpha_s}\right)\left(\frac{P_{Ms'st}}{P_{Mst}}\right)^{-\kappa_s} \tag{82}$$

$$M_{Hs'st} = \xi_{s's}\Psi\left(D_{Ms'st}\frac{P_{Hs't}}{P_{Ms'st}}\right) M_{s'st} \tag{83}$$

$$M_{Fs'st} = (1-\xi_{s's})\,\Psi\left(D_{Ms'st}\frac{P_{MFs'st}}{P_{Ms'st}}\right) M_{s'st} \tag{84}$$

$$
\begin{aligned}
1 &= \xi_{s's} \Upsilon \left(\frac{M_{Hs'st}}{\xi_{s's} M_{s'st}} \right) + (1 - \xi_{s's}) \Upsilon \left(\frac{M_{Fs'st}}{(1 - \xi_{s's}) M_{s'st}} \right) && (85) \\
P_{Ms'st} &= P_{Hs't} \frac{M_{Hs'st}}{M_{s'st}} + P_{MFs'st} \frac{M_{Fs'st}}{M_{s'st}} && (86) \\
P_{Mst} &= \left(\sum_{s'} \left(\frac{\alpha_{s's}}{\alpha_s} \right) P_{Ms'st}^{1-\kappa_s} \right)^{\frac{1}{1-\kappa_s}} && (87) \\
X_{st} &= C_{st}^{*} \left(\frac{P_{Xst}}{P_{Cst}^{*}} \right)^{-\eta_{Xs}} && (88) \\
P_{Xst} &= \frac{\epsilon_{Xs}}{\epsilon_{Xs} - 1} MC_{st} && (89) \\
P_{CFst} &= \frac{\epsilon_{Fst}}{\epsilon_{Fst} - 1} MC_{Cst} && (90) \\
P_{MFs'st} &= \frac{\epsilon_{Fst}}{\epsilon_{Fst} - 1} MC_{Ms'st} && (91) \\
Y_{st} &= C_{Hst} + \sum_{s'} M_{Hss't} + X_{st} && (92) \\
L_t &= \sum_{s} L_{st} && (93) \\
\Pi_t &= \sum_{s} \left(\left(C_{Hst} + \sum_{s'} M_{Hss't} \right) P_{Hst} \frac{1}{\epsilon_{Hst}} + X_{st} P_{Xst} \frac{1}{\epsilon_{Xs}} \right) && (94)
\end{aligned}
$$