Inflation Strikes Back: The Return of Wage to Price Pass-Through*

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Abstract

U.S. inflation has recently surged, with inflation reaching its highest readings since early 1980s. We examine the drivers of the rise in inflation, focusing on rising import prices, labor supply constraints and their interaction. We first develop a two-sector New Keynesian DSGE model with multiple shocks and substitution between production factors. Our model considers a finite number of domestic and foreign producers as in Atkeson and Burstein (2008) to capture the effect of foreign competition on firms' price setting. Markups are endogenous and firms pass through shocks incompletely due to the strategic interaction with their competitors. Using our calibrated two-sector model, we show that supply chain shocks can lead to higher wages on their own as firms substitute towards domestic labor. We find that around one third of post-pandemic wage growth can be explained with import price shocks which caused a substitution towards labor from imported inputs. Importantly, we show that a joint wage and import price shock has an *amplified* effect on inflation by making substitution between factors of production more difficult.

Our model implies a structural equation linking price changes to changes in marginal costs and competitors' prices. In the second part of the paper, we estimate the model-implied estimating equation using detailed industry-level data on producer prices and wages at the 6-digit NAICS level. We find that industries which faced a larger increase in their imported input prices also experienced higher wage growth—consistent with the substitution channel. Moreover, we find a stark increase in pass-through from wages to prices in the goods sector: a given level of wage growth is associated with a larger increase in prices in the 2020-21 period. Our analysis provides a unified explanation for both the missing inflation (2013-2019) and the high inflation period (2020-2022) and implies that alleviation of even one of the cost-push shocks would cause a moderation in inflation by making the input substitution channel more operational.

Keywords: Inflation dynamics, Phillips curve, pass-through, supply chains
JEL Classification: E24, E31

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1 Introduction

> *So we have now experienced an extraordinary series of shocks if you think about it. The pandemic, the response, the reopening, inflation, followed by the war in Ukraine, followed by shutdowns in China, the war in Ukraine potentially having effects for years here. So we're aware that a different set of forces are driving the economy, we have been obviously for quite a while.* **Chair Powell**

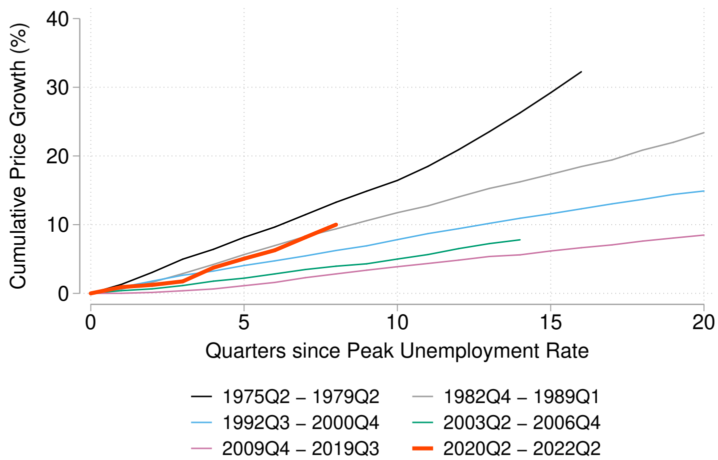
U.S. inflation has recently surged with annual CPI inflation reaching 9.1 percent in June 2022, its highest reading since November 1981. Many commentators have attributed this high and persistent level of inflation to several unprecedented developments, such as the COVID-19 pandemic, the war in Ukraine, and factory shutdowns in China (see quote above). To illustrate the high price growth, Figure 1 shows the increase in the core CPI price index for the past six expansions, starting at the quarter with the peak level of unemployment of the preceding recession. Price growth in the most recent expansion is markedly higher than in previous expansions: eight quarters after peak unemployment in 2020:Q2, prices have grown by 10 percent, following a trajectory similar to the 1980s expansion rather than the most recent periods.

In this paper, we examine the drivers of the rise in price inflation, focusing on two cost-based explanations: supply chain bottlenecks and labor supply constraints, which emerged at the onset of the COVID-19 pandemic.[1] Supply chain bottlenecks have led to an increase in import prices, driving up input costs. For example, Amiti et al. (2021) and LaBelle and Santacreu (2022) document that higher import prices and supply chain disruptions have led to higher U.S. producer prices. Additionally, wage growth has been strong last year, driven by tight labor market conditions and the declining desire to work. Our hypothesis is that in normal times, firms can substitute between labor and (imported) intermediate inputs, thus cushioning any cost shock due to one of the two factors.[2] Over the past decades, U.S. inflation has become more linked to global factors, as foreign competition and firms' ability to outsource have weakened the link between wage pressures and prices in the U.S. (see Forbes, 2019; Obstfeld, 2019). We argue that this substitution channel is less likely to be operational in the post-COVID economy due to the large and simultaneous inflationary shocks to both labor and intermediate inputs. As substitution has weakened, we expect cost-push pressures to be amplified compared to times when both shocks arise in isolation.

[1]While many factors likely have contributed to the surge in inflation, these two have been the most prominent explanations. See for example, NY Times Daily Business Briefing: Supply Chain Snags Continued to Drive Up Prices in December, January 12, 2022 and NY Times: Could Wages and Prices Spiral Upward in America? February 17, 2022.

[2]This substitution mechanism has been highlighted by Feenstra et al. (2018), Elsby et al. (2013). When

Figure 1: Evolution of Core CPI Inflation During Economic Expansions



Source: BLS and authors' calculations. Note: This figure plots the cumulative core CPI inflation (All items less food and energy, seasonally adjusted) against time, starting at the quarter of peak unemployment of a given recession, for the past six expansions.

We require a framework that allows us to examine the interaction between multiple shocks and the substitution between production factors to understand the current inflation dynamics. In the first part of the paper, we therefore develop a two-sector New Keynesian model with domestic and imported inputs to analyze the theoretical effects of an import price shock compared to a joint shock to import prices and wages. Our model allows for multiple simultaneous shocks and substitution between labor and intermediates. Intermediate inputs are a combination of domestic and foreign inputs, which again are substitutible. To capture the effect of foreign competition on firms' price setting, our model considers a finite number of domestic and foreign producers, which compete in a framework as in Atkeson and Burstein (2008). Markups are variable in this framework, and firms pass through shocks incompletely due to the strategic interaction with their competitors. We refer to the two sectors in the model as "Goods" and "Services", and assume that firms in the goods sector are subject to foreign competition in their output market, while services firms compete only domestically. Moreover, intermediate inputs account for a higher share of inputs in goods than in services. These sectoral differences generate heterogeneous responses of inflation across the two sectors.

We calibrate the model using standard parameters from the literature. The model contains two key parameters. The first one is the elasticity of substitution between labor and intermediates. When the two production factors are easily substituted, an exogenous increase

labor costs go up, firms can outsource production to other countries and import intermediate inputs.

in wages generates only modest price growth as firms can easily shift away from labor towards intermediates, moderating the pressure on marginal costs. The second key parameter is the elasticity of substitution between domestic and foreign intermediates. When substitution is high, firms can easily replace foreign inputs with domestic inputs. The strength of these two elasticities governs the extent to which firms can protect themselves against domestic wage pressures by substituting towards intermediates that are produced abroad.

We compute impulse responses in the calibrated model and obtain two key insights. First, we find that an import price shock on its own generates substantial wage inflation. Specifically, a 15 percent increase in imported input prices alone, in the range of recent import price increases, would generate wage inflation of about 1 percent, as firms substitute away from imported intermediates towards domestic intermediates and labor. Second, we study a combined shock to import prices and wages, where we model the latter as a wage markup shock such that wage inflation rises to about 3 percent. We find that the combined shock would generate at its peak price inflation of about 2.4 percent. Importantly, a separate import price and wage markup shock would lead, in total, to price inflation of only 2 percent. Thus, the simultaneity of the two shocks generates an *amplified* inflation response. This result suggests that the alleviation of only one of the shocks might be able to reduce both wage and price inflation substantially.

In the second part of the paper, we test the model's implications empirically. Our model implies a structural equation linking price changes to changes in marginal costs and competitors' prices. We estimate a reduced-form version of this equation in detailed industry-level data at the 6-digit NAICS level for the period 2013-2021. We obtain industry-level prices from the Producer Price Index (PPI) of the Bureau of Labor Statistics, and generate proxies for the change in firms' marginal costs. Specifically, we generate input price indices for each industry by combining domestic producer prices and import prices with the input-output matrix of the Bureau of Economic Analysis (BEA). We compute the change in industry wages from weekly wage data from the Quarterly Census of Employment and Wages (QCEW). To control for competitors' prices, we construct foreign competitors' prices using import unit values from the Census Bureau. We focus on foreign competitors' prices since our industry-level data do not allow us to control for within-industry domestic competitors. We analyze separately the goods sector and the services sector, consistent with the model, where our definition of the goods sector contains all traded industries, i.e., all industries with positive imports in some year. These industries are predominantly in manufacturing, with some in mining and agriculture. The services sector consists of all industries that never record positive imports and are hence non-traded.

Focusing first on the goods sector, we find that in the pre-COVID period a 10 percent increase in intermediate input prices was associated with a producer price increase of 2.4 percent while wage pass-through was virtually zero.[3] Pass-through rose significantly after the emergence of COVID-19. In 2021, a 10 percent increase in intermediate input prices and wages yielded U.S. producer price increases of 3.9 and 1.3 percent, respectively. This increase in the correlation between input costs and producer prices is consistent with a stronger price response when both shocks arrive simultaneously as suggested by the model. U.S. firms' prices are also more responsive to changes in foreign competitors' prices in 2021: in the pre-COVID period, a 10 percent rise in foreign competitors' prices is associated with a 0.5 percent increase of the producer prices by U.S. firms in an industry with the average import share of 31%. This pass-through rises to 2 percent in 2021. The higher correlation between foreign and U.S. producer prices suggests that firms are experiencing a similar set of shocks.

To test the model's implication that pass-through of input price shocks is higher when both wages and input costs rise at the same time, we run our regression specification with an interaction between the change in intermediate input prices and the change in wages. Consistent with the theory, we find a strong complementarity between the two: pass-through from wages to prices is 1.9 percentage points higher for every 1 percentage point increase in input prices. Our findings are robust to adding a proxy for domestic competitors' prices, which we construct from the domestic price index of the higher-level 4-digit industry for each 6-digit industry we analyze. They also hold when we add aggregated industry by time fixed effects to sweep out variation affecting the broader sector, for example higher demand for electronics. Our empirical analysis extends recent work by Heise et al. (2022), where we document declining pass-through from wages to prices due to import price competition, and shows that this trend has reversed.

We next turn to services and find an increase in wage pass-through from 6.5 percent pre-COVID to 16 percent in 2021. The pass-through of intermediate input costs remains 21 percent throughout the entire period. We do not find a positive interaction effect between wages and intermediate inputs, consistent with the very low elasticity of substitution in that sector in our model.

Our paper is closely related to recent work on inflation dynamics in the post-COVID period. Crump et al. (2022) re-examine the Phillips curve for the recent period and project underlying inflation to remain high due to strong wage growth. Di Giovanni et al. (2022) show that supply chain pressures and labor shortages have contributed to higher inflation in both the Euro area and the U.S. in the recent period, and analyze these effects through an input-output network. Our paper also relates to work examining the effects of imports on U.S.

[3] This finding is consistent with Heise et al. (2022), who do not find significant pass-through of wage changes to prices for the manufacturing sector between 2003 and 2016.

inflation. Jaravel and Sager (2019) and Bai and Stumpner (2019) show that Chinese imports led to a reduction in U.S. consumer prices. Amiti et al. (2019b) find that increased U.S. tariffs during the trade war period led to substantial increases in the prices of intermediate and final goods. More broadly, a large literature has examined the pass-through of cost shocks into prices. Amiti et al. (2019a) examine firms' price adjustment in response to changes in input prices and competitors' prices in Belgium, and Nakamura and Zerom (2010) study the pass-through of costs into prices in the coffee industry. Our paper focuses explicitly on the recent period. We show that changes in import competition, as well as a lower possibility to substitute between labor and intermediate inputs, contributed to the recent surge in inflation.

Our work is also related to studies estimating components of the Phillips curve using cross-sectional data, such as Hazell et al. (2021) and Beraja et al. (2019). We use heterogeneity across industries to estimate the pass-through of wage and input prices on producer prices.

The rest of the paper is organized as follows. Section 2 documents some aggregate facts regarding behavior of inflation, import prices, and wages. Section 3 introduces our New Keynesian DSGE model, which we calibrate and analyze quantitatively in Section 4. We derive a structural estimating equation in Section 5, which we take to industry-level data in Section 6. Finally, Section 7 concludes.

2 Aggregate Facts

Inflation behavior in the post-COVID period is strikingly different than in the recent expansions. In this section, we show that both wages and import prices have increased, suggesting that they contributed to the rise in inflation.

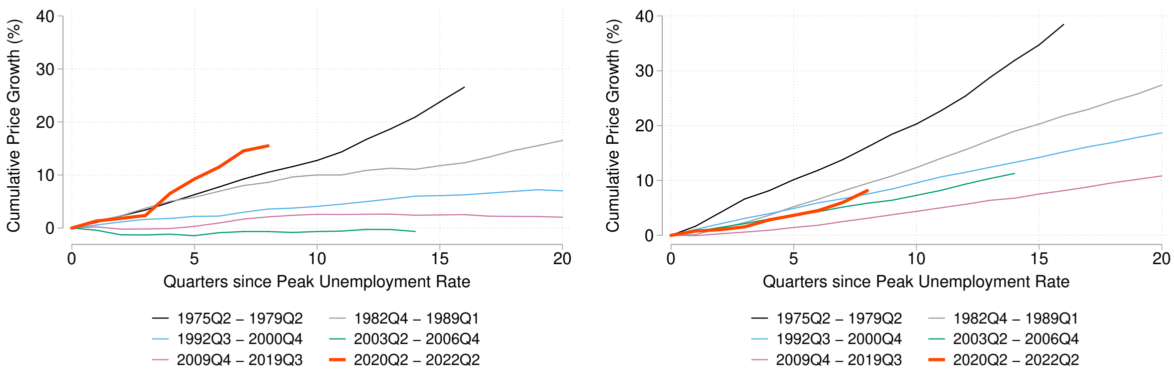
The left panel of Figure 2 shows the evolution of the core consumer price index for goods (core goods CPI) in the U.S. starting from the business cycle trough for each of the past six economic expansions. As the figure shows, the pick-up in core goods prices in the current expansion is the strongest across all expansions, including even the 1970s and the 1980s expansions. After only eight quarters since the unemployment peak, goods prices have risen by 16 percent. The right panel of Figure 2 shows the analogous figure for core services. The pick-up in services prices is significant but more modest, and tracks the recovery after the 2001 recession. This is a reversal of the typical inflation dynamics in the last 20 years, which were characterized by procyclical services price inflation and essentially no pick-up in goods price inflation despite declining unemployment (see, Heise et al. (2022)). On the contrary, goods inflation picked up briskly in 2021 and far exceeded services inflation.

Two important factors that are often referred to as the drivers of high inflation in the post-COVID period are rising import prices due to supply chain bottlenecks and strong wage

Figure 2: Evolution of Core Goods and Services CPI Inflation

(a) Core Goods over Time

(b) Core Services over Time



Source: BLS and authors' calculations. Note: The left panel plots the cumulative core goods CPI inflation (All items less food and energy, seasonally adjusted) against time, starting at the quarter of peak unemployment of a given recession. The right panel plots the cumulative core services inflation (All items less energy services) against time.

growth, both in goods and in services sectors. We next provide some evidence to illustrate these trends.

Table 1 shows the average 4-quarter change in both wage growth and import prices during the past four expansions. In row 1, we present wage growth from the Employment Cost Index (ECI), a measure of labor costs that includes benefits and takes into account compositional shifts in industry and occupation. According to the ECI, average four-quarter wage growth in the most recent expansion was 4.1 percent, exceeding the previous three expansions by about 1-2 percentage points. Row 2 shows average import price growth from the Import Price Index of the BLS. The average import price growth in the most recent expansion was 7 percent, compared to near zero in most other expansions. The final two rows show two end use categories within the import price index. We find a substantial growth for imported inputs that are used as industrial supplies, such as metals, chemicals, etc. The annual average growth rate was 27 percent for this group of products. These inputs are especially important because when the price of inputs increases, these costs are passed onto the prices of the goods that use them. The final row shows that capital goods prices have grown by 2 percent in the most recent expansion, while they fell in all prior expansions.

When faced with rising costs, firms are typically able to substitute between labor and intermediate inputs. Obstfeld (2019) and Forbes (2019) have argued that the transmission of domestic shocks to inflation has diminished over time due to the rise of global competition. This substitution mechanism allows firms to keep prices relatively stable, even in the face of increased input costs. However, we argue that this mechanism is likely to be less operational today due to large and simultaneous inflationary shocks.

Table 1: Wage and Import Price Growth

	Average 4-Quarter Change			
	1992:Q2-2000:Q4	2003:Q2-2006:Q4	2009:Q4-2019:Q3	2020:Q2-2022:Q1
Wage Growth (ECI)	3.4%	3.2%	2.2%	4.1%
Import prices (excl. petroleum)	0.0%	2.4%	0.3%	6.7%
- *Industrial supplies excl. petroleum*	2.0%	*10.3 %*	*0.7%*	27.2%
- *Capital goods*	−2.4%	−0.8%	−0.4%	2.2%
Core CPI	2.6%	2.2%	1.9%	4.8%

3 Model

Our theory builds on the standard New Keynesian DSGE model but introduces a CES production structure using labor and intermediate inputs. We allow firms to be either foreign or domestic, as in Heise et al. (2022). To capture the strategic interactions between domestic firms and foreign competitors, we allow for variable markups in the producer problem by assuming that there is only a finite number of firms, similar to Jaimovich and Floetotto (2008). We will use the model in the next section to analyze the impact of a cost shock to labor and intermediates on wage and price inflation. We argue that when the cost of both factors of production increases at the same time, firms can no longer substitute between the two to ameliorate the increase in marginal costs, which leads to larger price inflation.

The economy consists of four sets of agents. Households consume final consumption goods. A perfectly competitive final output firm aggregates differentiated products according to a CES aggregator. These products are sourced from retailers in two sectors: the goods-producing sector, which we refer to as manufacturing, and services. Retailers in each sector are monopolistic competitors subject to Rotemberg pricing frictions, and aggregate inputs from a continuum of industries. Each industry is populated by a finite number of producers. The producers combine labor and an intermediate input to produce a differentiated product. The intermediate input in turn is produced using imported intermediates and domestic intermediates in a roundabout production structure. We next describe these building blocks of the model in more detail.

3.1 The Household Sector

There is a continuum of households, indexed by τ. Households supply differentiated labor at nominal wage $W_t^{s,\tau}$ to the manufacturing and services sectors, indexed by $s \in \{M, S\}$. Each household τ maximizes the present discounted value of utility given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t U_t^\tau,$$

where β indicates the discount factor and household τ's period utility is

$$U^\tau(C_t^\tau, \ell_t^{M,\tau}, \ell_t^{S,\tau}) = \frac{1}{1-\sigma}(C_t^\tau - H_t)^{1-\sigma} - \frac{1}{1+\varphi}(\ell_t^{M,\tau})^{1+\varphi} - \frac{1}{1+\varphi}(\ell_t^{S,\tau})^{1+\varphi}.$$

In this equation, C_t^τ is the household's consumption, $\sigma > 0$ is the coefficient of relative risk aversion, $\varphi > 0$ is the inverse of the Frisch elasticity of labor supply, and $H_t = hC_{t-1}$ is the habit stock of the household, as in Smets and Wouters (2003). The labor supply is additively separable across the two sectors and given by $\ell_t^{s,\tau}$ for sector s.

Households maximize their consumption subject to the intertemporal budget constraint

$$C_t^\tau P_{f,t} + b_t B_t^\tau + Q_{t+1} A_{t+1}^\tau \leq W_t^{M,\tau} \ell_t^{M,\tau} + W_t^{S,\tau} \ell_t^{S,\tau} + B_{t-1}^\tau + A_t^\tau + P_{f,t} \Pi_t^\tau,$$

where $P_{f,t}$ is the price index of the final good. Household τ invests B_t^τ into a one-period bond with price b_t at time t. Following Cristiano et al. (2005), households also purchase A_{t+1}^τ of state-contingent securities with price Q_{t+1}. The state-contingent securities insure the households against fluctuations in household-specific labor income, and hence the labor income of household τ will be equal to aggregate labor income. Households own the firms and receive nominal dividends $P_{f,t}\Pi_t^\tau$.

We next discuss the household decisions in turn. We delegate all derivations of the model solutions to Appendix A.

Consumption and Savings Behavior. The solution to the household consumption-savings problem leads to the standard Euler equation

$$(C_t - hC_{t-1})^{-\sigma} = \beta E_t \left[\frac{1+R_t}{1+\pi_{t+1}} (C_{t+1} - hC_t)^{-\sigma} \right], \tag{1}$$

where R_t is the nominal interest rate on bonds and $\pi_t \equiv P_{f,t}/P_{f,t-1} - 1$ is the rate of consumer price inflation.[4]

[4]See Appendix A.1.1 for the derivations.

Labor Supply Decisions and Wage Setting. Households are wage setters in the labor market as in Smets and Wouters (2003). They face a labor demand curve of

$$l_t^{s,\tau} = \left(\frac{W_t^{s,\tau}}{W_t^s}\right)^{-\eta_t^s} L_t^s, \tag{2}$$

where labor demand L_t^s and the nominal wage in sector s, W_t^s, are given by

$$L_t^s = \left[\int_0^1 (\ell_t^{s,\tau})^{\frac{\eta_t^s-1}{\eta_t^s}} d\tau\right]^{\frac{\eta_t^s}{\eta_t^s-1}},$$

and

$$W_t^s = \left(\int_0^1 (W_t^{s,\tau})^{1-\eta_t^s} d\tau\right)^{1-\eta_t^s}.$$

The parameter η_t^s governs the markup in sector s and follows an exogenous process

$$\eta_{t+1}^s = (1-\gamma_\eta)\eta^s + \gamma_\eta \eta_t^s + \epsilon_{t+1}^{\eta,s} \tag{3}$$

where η^s is the markup in steady state and $\epsilon_t^{\eta,s}$ is a markup shock in sector s.

Households set wages subject to Rotemberg pricing frictions with a utility cost of changing price that is governed by a parameter ψ_w. The maximization problem leads to the following markup equation:

$$(\eta_t^s - 1)(C_t - hC_{t-1})^{-\sigma} w_t^s = \eta_t^s (L_t^s)^{(1+\varphi)-1} - \psi_w \pi_t^{s,w}(1+\pi_t^{s,w}) + E_t \beta \psi_w \pi_{t+1}^{s,w}(1+\pi_{t+1}^{s,w}), \tag{4}$$

where $w_t^s \equiv W_t^s / P_{f,t}$ is the real wage and $\pi_t^{s,w} \equiv W_t^s / W_{t-1}^s - 1$ is the rate of wage inflation in sector s.[5]

3.2 Final Output Firm

The final output good is a Cobb-Douglas aggregate of two sectoral goods, manufacturing and services:

$$Y_{f,t} = (Y_{f,t}^M)^{\gamma^M} (Y_{f,t}^S)^{\gamma^S}, \tag{5}$$

where γ^M and γ^S is the manufacturing share of expenditures in each sector, $\gamma^M + \gamma^S = 1$. Both manufacturing and services are a CES aggregate of a continuum of products $j \in [0,1]$:

$$Y_{f,t}^s = \left(\int_0^1 y_{f,t}^s(j)^{\frac{\theta-1}{\theta}} dj\right)^{\frac{\theta}{\theta-1}}. \tag{6}$$

[5] See Appendix A.1.2 for the derivations.

where θ is the elasticity of substitution across products j. Cost minimization implies that the final demand for product j is

$$y^s_{f,t}(j) = \gamma^s \left(\frac{P^s_{f,t}(j)}{P^s_{f,t}}\right)^{-\theta} \left(\frac{P_{f,t}}{P^s_{f,t}}\right) Y_{f,t}, \tag{7}$$

where $P^s_{f,t} = (\int_0^1 P^s_{f,t}(j)^{1-\theta} dj)^{1/(1-\theta)}$ is the sectoral price index, and the consumer price index $P_{f,t}$ is a combination of the sectoral price indices[6]

$$P_{f,t} = \left(\frac{1}{\gamma^M}\right)^{\gamma^M} \left(\frac{1}{\gamma^S}\right)^{\gamma^S} (P^M_{f,t})^{\gamma^M} (P^S_{f,t})^{\gamma^S}. \tag{8}$$

3.3 Retailers

Each product is sold by a retailer j. Retailers aggregate a continuum of industries $i \in [0,1]$ according to

$$y^s_{f,t}(j) = \left(\int_0^1 x^s_t(j,i)^{\frac{v-1}{v}} di\right)^{\frac{v}{v-1}}, \tag{9}$$

where v is the elasticity of substitution between industries and $x^s_t(j,i)$ is the quantity of industry i used by retailer j in sector s. The retailers are monopolistic competitors, taking price indices as given, and face a quadratic price adjustment cost a la Rotemberg with price adjustment parameter ψ_p. We denote the cost of the input of industry i by $P_{x,t}(j,i)$. Given demand (7) and solving for a symmetric equilibrium with $j = j'$ and $i = i'$, maximization of real profits results in the first order condition

$$(\theta - 1) = \theta \frac{p^s_{x,t}}{p^s_{f,t}} - \psi_p \left(1 + \pi^s_t\right) \pi^s_t + \beta \psi_p E_t \left[\frac{(C_{t+1} - hC_t)^{-\sigma}}{(C_t - hC_{t-1})^{-\sigma}} \frac{Y_{f,t+1}}{Y_{f,t}} \left(1 + \pi^s_{t+1}\right) \pi^s_{t+1}\right], \tag{10}$$

where $p^s_{x,t} \equiv P^s_{x,t}/P_{f,t}$, $p^s_{f,t} \equiv P^s_{f,t}/P_{f,t}$, sectoral inflation is $\pi^s_t = P^s_{f,t}/P^s_{f,t-1} - 1$, and we have omitted the i and j indices due to symmetry.[7]

3.4 Intermediate Goods Firms

Each industry i consists of a finite number of intermediate goods firms indexed by k that produce for retailer j in sector s. The finite number of firms allows for strategic interactions, which will generate potentially incomplete pass-through of shocks. We build on the canonical model by Atkeson and Burstein (2008) and its application in Heise et al. (2022). Firms can

[6] See Appendix A.2 for the derivations.
[7] See Appendix A.3 for the derivations.

either be domestic, D, or foreign, F, and the total number of these firms is N_D and N_F, respectively.

The production of intermediate goods firms is aggregated to the industry level according to

$$x_t^s(j,i) = (N^s)^{\frac{1}{1-\mu}} \left(\sum_{k=1}^{N_D^s} x_t^s(j,i,k)^{\frac{\mu-1}{\mu}} + \sum_{k=1}^{N_F^s} x_t^s(j,i,k)^{\frac{\mu-1}{\mu}} \right)^{\frac{\mu}{\mu-1}} \tag{11}$$

where μ is the elasticity of substitution between firms and $N^s = N_D^s + N_F^s$. As in Jaimovich and Floetotto (2008), we include the scale term $(N^s)^{1/(1-\mu)}$ to ensure that there is no variety effect, which implies that, in an equilibrium in which all firms are symmetric, $N^s x_t^s(j,i,k) = x_t^s(j,i) = x_t^s(j)$. As in Atkeson and Burstein (2008), we assume that $\mu > v$ so that it is easier to substitute across firms within industries than across industries.

Demand

Firms engage in Bertrand competition, and set a producer price of $P_{x,t}^s(j,i,k)$. Demand for firm k's output is

$$x_t^s(j,i,k) = \left(\frac{P_{x,t}^s(j,i,k)}{P_{x,t}^s(j,i)} \right)^{-\mu} \frac{x_t^s(j,i)}{N^s}, \tag{12}$$

where $P_{x,t}^s(j,i,k) = P_{x,t}^s(j,i) = P_{x,t}^s(j) \equiv P_{x,t}^s$ in a completely symmetric equilibrium, and

$$P_{x,t}^s(j,i) = (N^s)^{\frac{1}{\mu-1}} \left(\sum_{k=1}^{N_D^s} P_{i,t}^s(j,i,k)^{1-\mu} + \sum_{k=1}^{N_F^s} P_{i,t}^s(j,i,k)^{1-\mu} \right)^{\frac{1}{1-\mu}} \tag{13}$$

is the industry price index.[8] We will analyze the behavior of this producer price index at the industry-level in our empirical analysis below.

Production

We assume that firms combine two factors of production: intermediate inputs and labor. These factors of production are imperfectly substitutible via a CES production structure. Our setup will allow us to analyze the substitution patterns in response to a cost shock to one or both of the factors.

Domestic intermediate firm k supplying retailer j in sector s has a production function

$$x_t^s(j,i,k) = \left[(A_t L_t^s(j,i,k))^{\frac{\rho_s-1}{\rho_s}} + \Lambda_s^{\frac{1}{\rho_s}} D_t^s(j,i,k)^{\frac{\rho_s-1}{\rho_s}} \right]^{\frac{\rho_s}{\rho_s-1}}, \tag{14}$$

[8] See Appendix A.4.1 for the derivations.

where A_t is aggregate labor productivity, which is common across sectors, and $L_t^s(j,i,k)$ and $D_t^s(j,i,k)$ are labor and intermediate inputs used by the firm. The parameter ρ_s is the sector-specific elasticity of substitution between the inputs. When one of the factors of production increases in cost, firms substitute towards the other factor, where the strength of the effect is governed by ρ_s. The parameter Λ_s is a constant that we will use to match the share of intermediates in production in steady state.

The intermediate input $D_t^s(j,i,k)$ is in turn a composite of domestic and foreign inputs, which are combined according to

$$D_t^s(j,i,k) = \left[M_t^s(j,i,k)^{\frac{\xi-1}{\xi}} + Z_t^s(j,i,k)^{\frac{\xi-1}{\xi}} \right]^{\frac{\xi}{\xi-1}} \tag{15}$$

where $M_t^s(j,i,k)$ is an imported intermediate input and $Z_t^s(j,i,k)$ is an aggregate of domestic intermediate inputs. The equation highlights that firms can adjust to a change in imported input costs by substituting towards the domestic input with an elasticity of substitution that is governed by ξ.

The imported intermediate input $M_t^s(j,i,k)$ is supplied with an exogenous price $P_{x,imp,t}$, which is common across the two sectors. The relative import price $p_{x,imp,t} \equiv P_{x,imp,t}/P_{f,t}$ follows an exogenous process

$$\ln(p_{x,imp,t+1}) = (1-\gamma_P)\ln(p_{x,imp}) + \gamma_P \ln(p_{x,imp,t}) + \epsilon_{t+1}^P, \tag{16}$$

where $p_{x,imp}$ is the relative import price in steady state and ϵ_t^P is an import price shock. We will calibrate $p_{x,imp}$ below to match the empirically observed imported input share.

The domestic input $Z_t^s(j,i,k)$ is assembled using all industries' output via a roundabout production technology that combines all industries as in equation (9), and combines sectors in the same way as the consumer good in equations (5) and (6). We assume that the domestic input is produced with the same weights γ_M, γ_S as the consumer good. This structure leads to a price index for domestic inputs of

$$P_{x,dom,t} = \left(\frac{1}{\gamma^M}\right)^{\gamma^M} \left(\frac{1}{\gamma^S}\right)^{\gamma^S} (P_{x,t}^M)^{\gamma^M} (P_{x,t}^S)^{\gamma^S}, \tag{17}$$

analogous to the equation for the consumer price index (8), but using the sectoral producer prices $P_{x,t}^s$ defined above.[9] Since both sectors use the same input basket, the domestic input price index is the same in both sectors. We assume that only domestic firms demand domestic intermediates.

[9] See Appendix A.4.2 for the derivations.

Domestic intermediate input producers optimally choose their input bundle of domestic and foreign intermediates, and then optimize over intermediates and labor to minimize costs. Cost minimization implies that marginal costs of domestic firm k are

$$MC^s_{D,t} = \left[(W^s_t/A_t)^{1-\rho_s} + \Lambda_s(P^s_{x,input,t})^{1-\rho_s}\right]^{1/(1-\rho_s)}, \tag{18}$$

where $P_{x,input,t}$ is the intermediate input price index. This price index aggregates the prices of domestic and foreign inputs according to[10]

$$P^s_{x,input,t} = \left[(P^s_{x,dom,t})^{1-\xi} + (P_{x,imp,t})^{1-\xi}\right]^{1/(1-\xi)}. \tag{19}$$

Real marginal costs are defined as $mc^s_{D,t} \equiv MC^s_{D,t}/P_{f,t}$.

We assume that foreign intermediate firms face an exogenous process for real marginal costs, $mc^s_{F,t} \equiv MC^s_{F,t}/P_{f,t}$, given by

$$\ln(mc^s_{F,t+1}) = (1-\gamma_F)\ln(mc^s_F) + \gamma_F \ln(mc^s_{F,t}) + \epsilon^F_{t+1}, \tag{20}$$

where mc^s_F is the foreign firm's marginal cost in steady state and ϵ^F_t is a marginal cost shock.

Profit maximization implies that producers set producer prices as

$$P_{x,t}(j,i,k) = \frac{\mathcal{E}^s_t(j,i,k)}{\mathcal{E}^s_t(j,i,k)-1} MC^s_{k,t}, \tag{21}$$

where $k \in \{D, F\}$, and

$$S^s_t(j,i,k) = \left(\frac{1}{N^s}\right)\frac{P^s_{x,t}(j,i,k)^{1-\mu}}{P^s_{x,t}(j,i)^{1-\mu}} \tag{22}$$

is the market share of firm k, and $\mathcal{E}^s_t(j,i,k) = \mu(1 - S^s_t(j,i,k)) + \nu S^s_t(j,i,k)$ is the effective elasticity of substitution faced by the firm. Equation (21) highlights that firms set a variable markup $\mathcal{M}_t(j,i,k) \equiv \mathcal{E}^s_t(j,i,k)/(\mathcal{E}^s_t(j,i,k)-1)$ over marginal costs, which depends on their market share. Firms with a higher market share face a lower effective elasticity of substitution, and hence set higher markups.[11]

Going forward, we will assume that foreign firms operate only in the manufacturing sector, while the services sector contains only domestic firms. This assumption is consistent with the empirical analysis below, where a number of industries, mostly in services, do not record any imports and hence no competition by foreign firms.

[10]See Appendix A.4.3 for the derivations.

[11]See Appendix A.4.4 for the derivations.

3.5 Monetary Authority

We close the model by assuming that a central bank sets monetary policy based on a Taylor rule. This rule is given by

$$R_{t+1} = \varrho R_{t-1} + (1-\varrho)R + (1-\varrho)(\Phi_\pi \pi_{t+1} + \Phi_y(\ln(Y_t) - \ln(Y))) + \epsilon^M_{t+1}, \tag{23}$$

where ϕ_π and ϕ_y are the central bank's weights on inflation and on domestic gross output, respectively. The gross output Y_t includes the output by domestic producers going both to consumers and to other firms, and Y is its steady state value. Monetary policy shocks are represented by ϵ^M_{t+1}.

3.6 Aggregation

We consider an equilibrium in which all domestic and foreign firms are symmetric, but allow the two groups to differ in terms of their marginal costs. Thus, a domestic producer will set price $P^s_{D,x,t}$ and a foreign producer sets price $P^s_{F,x,t}$. Total output by producers in sector s, Y^s_t, is equal in equilibrium to the total demand for domestic output by consumers, from other firms, and for the price adjustment cost:

$$Y^s_t = \frac{N^s_D}{N^s}\left(\frac{P_{D,x,t}}{P_{x,t}}\right)^{-\mu}\left(\gamma^s\left(\frac{P_{f,t}}{P^s_{f,t}}\right)C_t + \gamma^s\frac{\psi_p}{2}(\pi^s_t)^2 C_t + \gamma^s\left(\frac{P^s_{x,dom,t}}{P^s_{x,t}}\right)Z^s_t + \gamma^s\left(\frac{P^{s'}_{x,dom,t}}{P^s_{x,t}}\right)Z^{s'}_t\right).$$

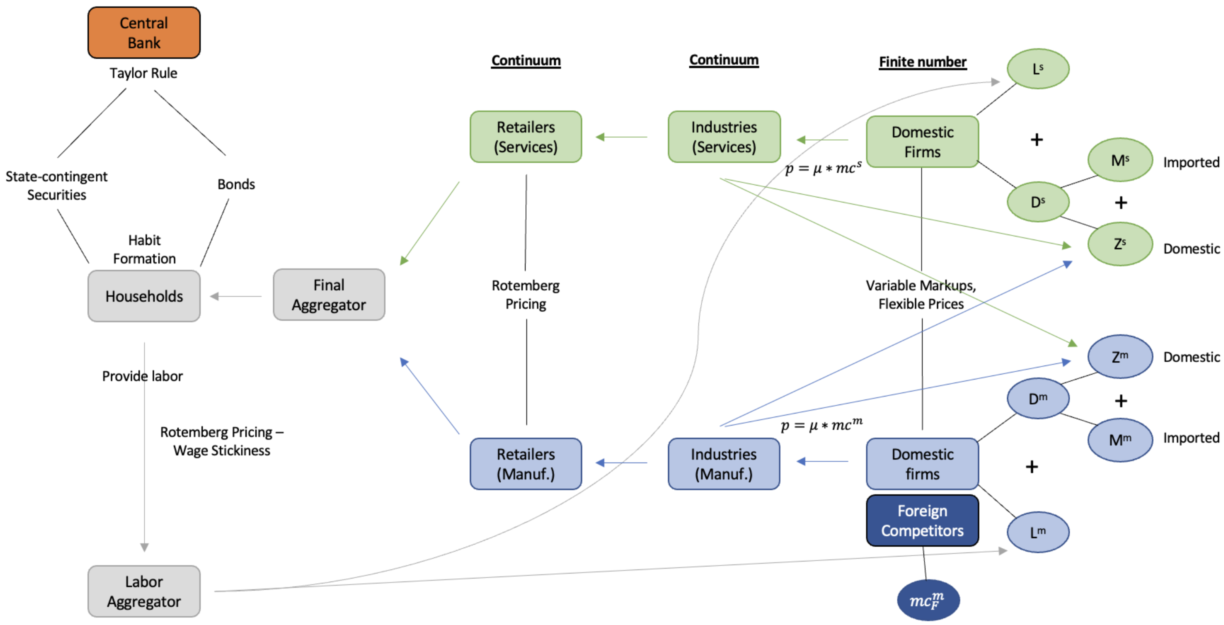
The first term, $(N^s_D/N^s)(P_{D,x,t}/P_{x,t})$, represents the share of total demand that is satisfied by domestic producers. This share depends on the number of domestic producers in sector s, N^s_D, and their price relative to the industry price index, which also includes foreign firms. The term in parentheses represents the output demand from three sources. The first term in parentheses is the demand from consumers, where in equilibrium $Y_{f,t} = C_t$. The second term is the output needed by retailers to cover the price adjustment. The third and fourth term are the input demands by sector s and s' from sector s, which depend on the price of sector s relative to the domestic input price index. The total demand for intermediates from sector s is given by

$$Z^s_t = \Lambda_s\left(\frac{P^s_{x,dom,t}}{P^s_{x,input,t}}\right)^{-\xi}\left(\frac{P^s_{x,input,t}}{MC^s_{D,t}}\right)^{-\rho_s} Y^s_t.$$

Total gross output is

$$Y_t = Y^M_t + Y^S_t.$$

Figure 3: Model Diagram



Note: This figure summarizes key components of the model. Households are represented by gray cells, the central bank in orange, while the green and blue cells show the manufacturing and services sector, respectively. The dark blue box highlights foreign competitors.

Aggregate labor demand in sector s is equal to

$$L_t^s = A_t^{\rho_s - 1} \left(\frac{W_t^s}{MC_{i,t}^s} \right)^{-\rho_s} Y_t^s,$$

which must equal the total supply of labor to that sector given by (4).[12] We list all equilibrium conditions in Appendix A.6.

Figure 3 summarizes the components of the model. The gray cells show the household side. Households face a trade-off between consumption of final goods and savings, and base their decision on the interest rate set by the monetary authority, shown here in orange. The central bank sets monetary policy using a Taylor rule. The blue and green cells show the manufacturing and services sectors, respectively. Both sectors are populated by a continuum of retailers, which aggregate a continuum of industries that are populated by a finite number of producers. The producers assemble labor and intermediate inputs, where the latter are a

[12]See Appendix A.5 for the derivations.

combination of the labor supplied by households and imported inputs in both sectors. In the manufacturing sector, domestic firms face competition from foreign producers, which have an exogenous marginal cost process.

4 Quantitative Analysis

In this section, we calibrate our two-sector model using standard parameters and perform counterfactual analysis. We show that an import price shock on its own can lead to substantial wage and price inflation. We then demonstrate that a joint shock to import prices and wages has an amplified effect by muting the substitution channel.

4.1 Calibration

We set standard values for a number of parameters, and summarize the parameter values in Table 2. We choose the risk aversion parameter, inverse elasticity of work effort, discount factor, wage markup and habit parameter as in Smets and Wouters (2003), and obtain $\sigma = 1.371$, $\phi = 2.491$, $\beta = 0.99$, $\eta_M = \eta_S = 3$, and $h = 0.595$.

To calibrate the weight on labor, Λ_s, we define the labor share λ_s in steady state as

$$\lambda_s \equiv \frac{(w^s/A)^{1-\rho_s}}{(w^s/A)^{1-\rho_s} + \Lambda_s (p^s_{i,input})^{1-\rho_s}}, \tag{24}$$

where variables are without a time subscript to indicate a steady state. Given a calibrated λ_s, we can back out the parameter values Λ_s in steady state. We set the labor share in goods and services from the average share of labor costs relative to total costs in disaggregated industry-level data, described in more detail below, using the period 2013-2021. We obtain $\lambda_M = 0.31$ and $\lambda_S = 0.60$, and hence labor is significantly more important in services than in goods.

To calibrate the steady state relative import price, $p_{x,imp}$, we define the import share α in steady state as

$$\alpha \equiv \frac{(p_{x,imp})^{1-\xi}}{(p^s_{x,dom})^{1-\xi} + (p_{x,imp})^{1-\xi}}, \tag{25}$$

where $p_{x,dom} \equiv P_{x,dom}/P_f$. We set the import share α to match the average share of imported input costs in intermediate costs across industries in disaggregated industry-level data, using the period 2013-2021, and calibrate $\alpha = 0.10$. Given this parameter, we can then back out $p_{x,imp}$ in steady state.

For the elasticity of substitution across final goods, we follow Cristiano et al. (2005) and set $\theta = 6$. As in Atkeson and Burstein (2008) and Amiti et al. (2019a), we set the elasticity of substitution across firms to $\mu = 10$. They build on survey evidence by Anderson and van Wincoop (2004), which suggests that the elasticity across firms is likely to be in the range of 5 to 10. We follow the conventional calibration in the earlier papers and set the elasticity of substitution across industries to $\nu = 1$.

The consumption share of goods is obtained from the BEA. We average the goods share over time from 1970 to 2022 and obtain an estimate of $\gamma_M = 0.35$. It follows that the share of services must then be $\gamma_S = 0.65$. We calibrate the adjustment cost parameter for prices following Keen and Wang (2007). Assuming a steady state markup of 20%, they find that at a value of $\Psi_P = 72$, a simple model with Rotemberg adjustment costs corresponds to a Calvo model with a price adjustment frequency of 12 to 15 months, consistent with empirical evidence. We assume that the frequency of wage adjustment is similar to the adjustment of prices and choose $\Psi_w = 72$ as well. We specify the Taylor rule based on estimates by Carvalho et al. (2021), who follow a similar procedure as Clarida et al. (2000). For the Greenspan-Bernanke era, they find a Taylor rule persistence parameter of $\varrho = 0.8$, a weight on inflation of $\Phi_\pi = 1.4$, and a weight on the output gap of $\Phi_y = 0.95$

We follow Atkeson and Burstein (2008) to calibrate the number of firms. They set the number of firms to 20. Since there is very little guidance on the right number, we perform robustness checks of the model to analyze the impact of varying in the number of firms. In the goods sector, we assume that 10 percent of the firms are foreign competitors, matching the share of foreign inputs in all intermediate inputs. There are no foreign competitors in services. These choices lead to $N_D^M = 18$, $N_D^S = 20$, $N_F^M = 2$, and $N_F^S = 0$.

Table 2: Calibration Summary

Parameter	Description	Value	Source
σ	Risk aversion	1.371	Smets and Wouters (2003)
ϕ	Inverse elasticity of work effort	2.491	Smets and Wouters (2003)
β	Discount factor	0.99	Smets and Wouters (2003)
η_M, η_S	Wage markup	3	Smets and Wouters (2003)
h	Habit parameter	0.595	Smets and Wouters (2003)
λ_M, λ_S	Labor share goods (services)	0.31 (0.6)	Census Bureau, authors' calculations
α	Imported input share	0.10	Census Bureau, authors' calculations
θ	Elasticity final goods	6	Cristiano et al. (2005)
μ	Elasticity across firms	10	Atkeson and Burstein (2008)
ν	Elasticity across industries	1	Atkeson and Burstein (2008)
γ_M, γ_S	Consumption share goods (services)	0.35 (0.65)	BEA, authors' calculations
Ψ_P	Adjustment costs prices	72	Keen and Wang (2007)
Ψ_W	Adjustment costs wages	72	Assumed same as prices
ϱ	Taylor rule persistence	0.8	Carvalho et al. (2021)
Φ_π	Taylor rule weight on inflation	1.4	Carvalho et al. (2021)
Φ_y	Taylor rule weight on output	0.95	Carvalho et al. (2021)
N_D^M, N_D^S	Domestic firms goods (services)	18 (20)	Atkeson and Burstein (2008)
N_F^M , N_F^S	Foreign firms goods (services)	2 (0)	Atkeson and Burstein (2008)
ρ_M, ρ_S	Elasticity labor v. intermediates	3 (1.5)	Chan (2021), authors' calculations
ξ	Elasticity domestic v. foreign	3	Feenstra et al. (2018)

Two key sets of parameters remain to be determined. The first is the elasticity of substitution between labor and intermediates, ρ_s. This parameter is important because it governs to what extent firms can substitute between inputs when hit by a shock, and hence the importance of the substitution channel. We set this parameter based on Chan (2021), who estimates using Danish data that labor and intermediates are gross substitutes. He estimates elasticities of substitution in the range of 1.5 to 4 across broad industries, and we therefore choose $\rho_M = 3$. We assume a lower elasticity between labor and intermediates in services, and set $\rho_S = 1.5$.

The second key parameter is the elasticity of substitution between domestic and foreign intermediates, ξ. This parameter governs to what extent firms can switch to domestic intermediates in the event of a shock to foreign inputs. Feenstra et al. (2018) estimate this elasticity to be in the range of 1 to 4. Since we prefer this elasticity to be at least as high as the elasticity of substitution between labor and interemdiates, we set it to $\xi = 3$.

Our calibration implies that the model contains four key differences between the goods and the services sector. First, services account for a larger share of the consumption basket and of firms' inputs, $\gamma_M > \gamma_S$. Second, the labor share is lower in the goods sector, $\lambda_M < \lambda_S$, making intermediates more important. As a result, shocks to input prices will have a larger direct effect on goods. Third, it is easier to substitute between labor and intermediates in the goods sector, $\rho_M > \rho_S$. Finally, only the goods sector contains foreign competitors. The presence of foreign competition dampens the response of domestic producers to domestic shocks since these firms partially adjust their markups to preserve market share.

We solve the model via a third-order approximation in Dynare to capture non-linear effects.

4.2 Results

We first examine the impact of an intermediate input price shock on inflation and show that it affects wages even in the absence of a labor market shock. We then analyze the effects of joint shocks to input prices and wages.

4.2.1 Intermediate Input Price Shock

We first consider effects of a positive intermediate input price shock on inflation by setting $\epsilon^P_{t+1} = 0.13$, in the range of the average increase in import prices during the current expansion from Table 1. We assume $\gamma_P = 0.9$, so the shock is quite persistent. Since foreign competitors were likely affected by the same shock, we generate a shock to foreign competitors' marginal costs, ϵ^F_{t+1}, so that domestic and foreign producers' market shares remain approximately constant in equilibrium.

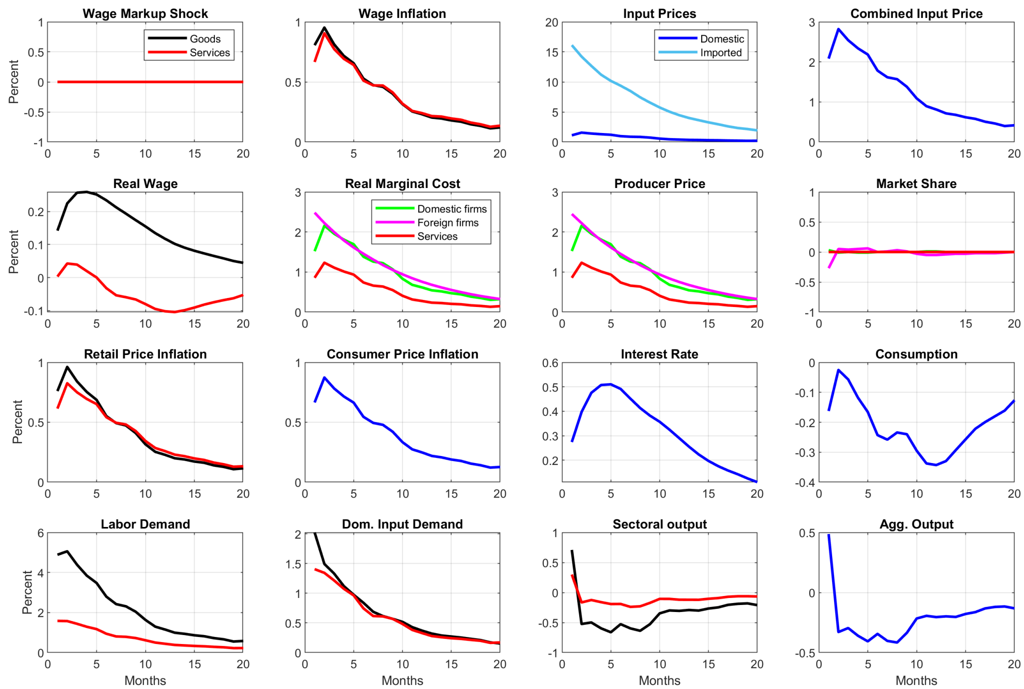
In Figure 4 we trace out the effect of the shock over the next 20 quarters. The third panel in the top row shows that the shock raises imported input prices by about 15 percent, and import prices only gradually return to the steady state. The figure shows a slight increase in domestic input prices due to a rise in equilibrium wages. In the bottom row, we see that the shock leads to substitution away from imported inputs towards labor and domestic inputs in both sectors. Output increases slightly on impact in both sectors as more inputs are now produced domestically. The shift towards domestic labor increases real wages and therefore marginal costs. As a result, there is significant wage inflation in both sectors of approximately 1 percent. Because market shares remain constant, the change in wages leads to almost complete pass-through into consumer price inflation, which also rises by 1 percent.

This experiment highlights that an import price shock on its own can generate substantial wage and price inflation. If supply chain bottlenecks prompt firms to source more from domestic suppliers, the resulting additional labor demand can put upward pressure on wages.

4.2.2 Joint Shock

We next investigate the impact of an import price shock that is accompanied by a wage markup shock. We interpret the wage markup shock as representing workers' increased reservation wage and the tighter labor market conditions in the recent period. Specifically,

Figure 4: Effect of Input Price Shock

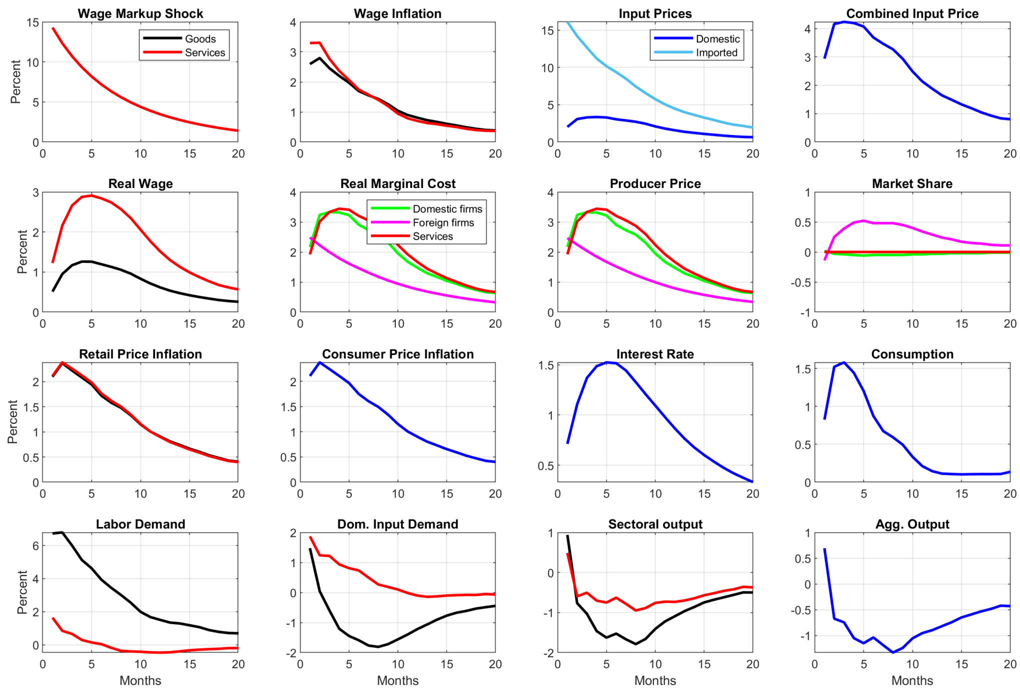


Source: Author's calculations. Figure shows the effect of an input price shock on key variables.

we choose for both sectors $\epsilon_{t+1}^{\eta,s} = 0.3$, which translates into a change in the wage markup of about 15 percent in both sectors. We calibrate this shock to generate a wage inflation of 3 percent in both sectors, which roughly matches the rise in wage inflation above its 2 percent baseline in the recent period. As for the import price shock, we assume a relatively persistent shock and set $\gamma_\eta = 0.9$.

The bottom row of panels in Figure 5 shows that in response to the joint shock there is substitution from intermediates towards labor. This shift towards labor is particularly strong in the manufacturing sector because the price of intermediate inputs rises by more than wages in that sector. Intermediate input prices rise due to the large imported input price shock and because of the rising wage in services, which are used to make domestic intermediates. Wages rise significantly in services, leading to a relatively stronger shift towards domestic inputs. The shift towards labor and the markup shock raise the real wage in both sectors and lead to wage inflation, as shown in the first row. We do not engineer an additional shock for foreign competitors in this exercise, and therefore the foreign competitors gain market share since their marginal cost does not rise as much as that of domestic firms. This shift

Figure 5: Effect of Joint Shock

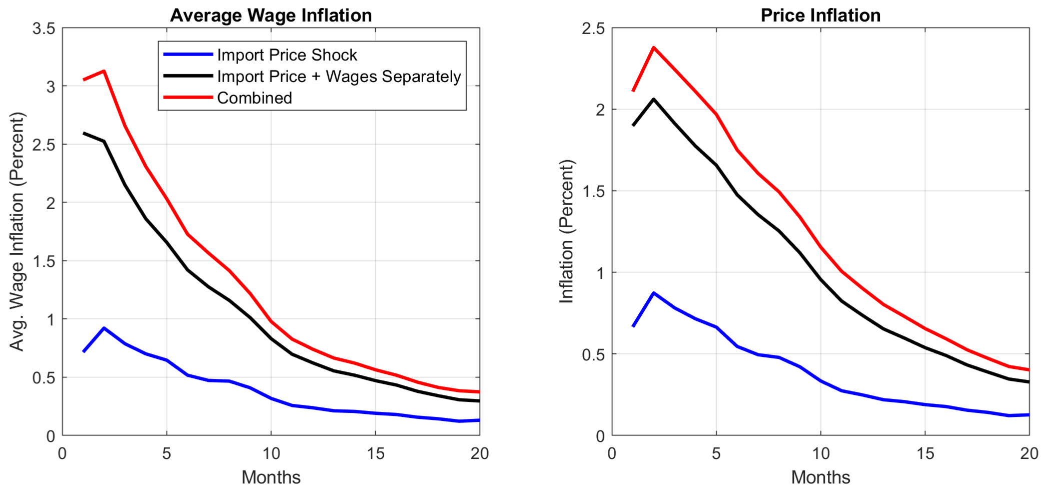


Source: Author's calculations. Figure shows the effect of a joint wage and input price shock on key variables.

of market share towards foreign firms dampens the effect of the shock. It also lowers the pass-through from wages to prices because firms reduce their markups to preserve market share. As a result, price inflation increases by less than wage inflation, reaching about 2 percent at its peak.

The joint wage and import price shock makes substituting between labor and intermediates less effective for domestic firms. Feenstra et al. (2018) describe that U.S. firms substitute away from labor and towards imported inputs to reduce costs, and Heise et al. (2022) show that firms' ability to use foreign inputs reduced the pass-through from wages to prices in the goods sector in the past two decades. As a result of the impaired substitution, a joint wage and import price shock has an amplified effect on inflation compared to two separate shocks. Figure 6 illustrates this point. The left panel shows the impulse response of the average wage inflation in the model, where the average is constructed using each sector's share in consumption. The right panel shows the impulse response of price inflation. We trace out the deviation of inflation in response to an import price shock alone in the blue line. The black line shows the sum of the impulse responses of a separate wage shock and

Figure 6: Effect of Joint Shock: Amplification



Source: Author's calculations. Figure shows the amplification effect of a joint shock on input prices and wage markup.

import price shock; i.e., we simulate the model twice, once for each shock, and add the resulting responses. We find that a joint wage and import price shock, illustrated by the red line, has a larger effect than the two shocks separately. When both shocks hit together, wage inflation is about 0.4 percentage points higher and price inflation is about 0.3 percentage points higher at the peak than when both shocks hit separately.

5 Linking the Theory to Data

We next derive a structural equation that we can use to test the model's implications in industry-level data. From equation (21), domestic producers set prices that are equal to marginal cost times a variable markup $\mathcal{M}_t(j,i,k) \equiv \mathcal{E}_t(j,i,k)/(\mathcal{E}_t(j,i,k)-1)$. Taking logs and differentiating this equation for a domestic firm, we obtain

$$d\ln(P_{x,t}(j,i,k)) = d\ln(MC^s_{D,t}) + d\ln(\mathcal{M}_t(j,i,k)), \tag{26}$$

which is a log-linear approximation of a price change. Using the expression for marginal costs, (18), a log-linear approximation yields

$$d\ln(MC^s_{D,t}) = \lambda^s_t\left[d\ln W^s_t - d\ln A_t\right] + (1-\lambda^s_t)d\ln P^s_{x,input,t},$$

where $\lambda_{s,t}$ is the labor share defined in (24).

For the second term, given our functional form of the demand elasticity $\mathcal{E}_t^s(j,i,k)$, we obtain

$$d\ln(\mathcal{M}_t(j,i,k)) = -\Gamma_t(j,i,k)\left[d\ln P_{x,t}(j,i,k) - d\ln P_{x,t}(j,i)\right],$$

where $\Gamma_t(j,i,k) = -(\partial \log \mathcal{M}_\sqcup(i,j,k)/\partial \log P_{x,t}(j,i,k)) \geq 0$ is the elasticity of the markup with respect to a firm's own price.[13] Plugging both into (26) and re-arranging, we obtain a firm's price change as a function of changes in the components of marginal costs and of changes in competitors' prices

$$\begin{aligned} d\ln(P_{x,t}(j,i,k)) = & \frac{\lambda_{s,t}}{1+\Gamma_t(j,i,k)}\left[d\ln W_t^s - d\ln A_t\right] + \frac{(1-\lambda_{s,t})}{1+\Gamma_t(j,i,k)} d\ln P_{x,input,t}^s \\ & + \frac{\Gamma_t(j,i,k)}{1+\Gamma_t(j,i,k)} d\ln P_{x,t}(j,i). \end{aligned} \tag{27}$$

Equation (27) illustrates how producers' prices are related to wages and input prices. The first and second terms in the equation reflect the direct effect of input costs on prices. We refer to this effect as the *marginal cost channel*. An increase in wages W_t^s that exceeds productivity growth passes through into prices with an elasticity that is proportional to the labor share in marginal costs, λ_t^s. Wage increases only raise prices to the extent that they exceed productivity growth. Changes in input costs pass through to prices with an elasticity that is proportional to $(1-\lambda_t^s)$, where input costs are themselves a combination of domestic and foreign intermediates according to equation (19). The third term in equation (27) captures the indirect effect on pass-through that operates via firms' markup adjustment. We refer to this effect as the *strategic complementarity channel*. An increase in a firm's competitors' prices $P_{x,t}(j,i)$ allows the firm to raise its prices itself by increasing its markup. The relative strength of the strategic complementarity channel and the marginal cost channel is modulated by the markup elasticity $\Gamma_t(j,i,k)$. Firms with a higher markup elasticity put a higher weight on the aggregate price index. The markup elasticity is increasing in a firm's market share holding everything else fixed, $d\Gamma_t(j,i,k)/dS_t(j,i,k) > 0$, and satisfies $\Gamma_t(j,i,k) = 0$ if $S_t(j,i,k) = 0$.

While equation (27) is a standard pass-through equation, it does not account for the non-linearity of the response due to the substitution between labor and intermediates. In particular, the labor share $\lambda_{s,t}$ adjusts in response to a shock: when import prices rise, firms substitute towards labor, raising the labor share. We therefore also perform a second-order approximation to the marginal cost term to derive the following non-linear estimating

[13] See Appendix A.7 for the derivation.

equation

$$
\begin{aligned}
d\ln(P_{x,t}(j,i,k)) = {} & \frac{\lambda_{s,t}}{1+\Gamma_t(j,i,k)}\left[d\ln W_t^s - d\ln A_t\right] + \frac{(1-\lambda_{s,t})}{1+\Gamma_t(j,i,k)} d\ln P^s_{x,input,t} \\
& + \frac{(\rho_s-1)\lambda_{s,t}(1-\lambda_{s,t})}{1+\Gamma_t(j,i,k)}\Big\{ (d\ln W_t^s - d\ln A_t)\, d\ln P_{x,input,t} \\
& - \frac{(d\ln W_t^s - d\ln A_t)^2}{2} - \frac{(d\ln P_{x,input,t})^2}{2}\Big\} + \frac{\Gamma_t(j,i,k)}{1+\Gamma_t(j,i,k)} d\ln P_{x,t}(j,i).
\end{aligned}
$$

This equation contains in the second row the interaction between the wage change and the input price change and in the third row quadratic terms of the wage change and the input price change. The negative sign of the quadratic terms highlights that, absent the interaction effect, the response of producer prices to a shock is smaller than that implied by the linear effect, due to the possibility to substitute. The importance of the substitution rises with the elasticity of substitution ρ_s and with the product of the shares of the two inputs, $\lambda_{s,t}(1-\lambda_{s,t})$. When both shares are relatively equal, substitution is strongest.

6 Empirical Analysis

6.1 Reduced-Form Specification

We now estimate a reduced form version of the structural equations derived in the previous section in industry-level data to test for the presence of the amplification channel. Going forward, we denote industry-level variables using the subscript i, and drop the sector subscripts for ease of notation. Our reduced-form estimating equation of (27) is

$$
\Delta\ln(P_{it}) = \beta_1\Delta\ln W_{it} + \beta_2\Delta\ln A_{it} + \beta_3\Delta\ln P_{it,input} + \beta_4\Delta\ln P_{it,imp} + \alpha X_{it} + \delta_i + \psi_t + \epsilon_{it}, \quad (28)
$$

where all variables are at the quarterly level and the difference operator indicates four quarter changes.

We construct the industry-level producer prices P_{it} from the Producer Price Index (PPI), which we have at the 6-digit North American Industrial Classification System (NAICS) level. The PPI measures the price received by domestic producers for their goods and services, comprising both final goods and intermediate goods. It is constructed by the Bureau of Labor Statistics (BLS) from a monthly survey of establishments representing nearly the entire goods sector and 70 percent of services. We rely on disaggregated industry data because constructing input prices is not possible at the sector or economy-wide level, since we would not be able to distinguish inputs from outputs. We aggregate the monthly PPI data to the quarterly level and match it with some of the data series that are only available at the quarterly level, such as wages and productivity. Our sample comprises 530 industries for the period 2013:Q1 to 2021:Q3.[14] Note that in this regression β_1 to β_4 cannot be interpreted as structural coefficients since we only have industry-level data.

We obtain quarterly industry wages, W_{it}, as the average weekly earnings from the Quarterly Census of Employment and Wages (QCEW) from the BLS. In principle, hourly earnings would be preferable to account for changes in hours worked. In practice, however, using the QCEW has several advantages over other datasets, such as greater coverage of establishments and industries (see Heise et al. (2022)).

We construct industry-level labor productivity, A_{it}, using industries' real value added from the Bureau of Economic Analysis (BEA). While the BLS provides disaggregated industry-level productivity measures, these are only available at an annual basis and with significant delay. We obtain quarterly real value added for 50 2-digit and 3-digit industries from the BEA, and divide by each industry's number of workers from the QCEW to obtain real value added per worker. For each 6-digit NAICS industry in our sample, we assign the real value added per worker of the corresponding 2-digit or 3-digit industry. We run an unrestricted regression where the coefficients on wages and productivity are allowed to differ, but examine a restricted regression below where $\beta_1 + \beta_2 = 0$, as in the theory.

We construct an industry's input cost index, $P_{it,input}$, as a weighted average of the domestic input price index and the imported input price index, consistent with equation (19). Specifically, the change in industry input prices is

$$\Delta \ln(P_{it,input}) = \alpha_{i,2012} \sum_n w_{n,i,2012} \Delta \ln(P_{nt,imp}) + (1 - \alpha_{i,2012}) \sum_n w_{n,i,2012} \Delta \ln(P_{nt}). \quad (29)$$

where $\alpha_{i,2012}$ is the industry's share of intermediate imported inputs in total material costs in 2012. The change in the domestic input price is constructed as the change in the log PPI across all industries n that provide inputs to industry i, where the weights are the time-invariant cost shares from the 2012 input-output table from the BEA.[15] We omit the domestic input industry n that is the same as industry i since we cannot disentangle the own industry's input prices from its output prices using our industry-level data.[16] We construct the imported input price index of industry i analogously as a weighted average over the

[14]We do not include earlier years due to revisions in the Census trade codes and NAICS codes, which make a consistent mapping from import prices to 6-digit PPI codes over longer time horizons more difficult.

[15]The latest input-output table with sufficiently disaggregated industries available is 2012. It comprises 405 BEA industries, which are mapped to 6-digit NAICS codes.

[16]As an example, if the auto industry uses 70 percent rubber and 30 percent steel, its domestic input price index will be constructed as 0.7 times the change in the log rubber price plus 0.3 times the price of the log steel price.

import price indices $P_{nt,imp}$ of all industries n that provide inputs to industry i. Since the import price indices provided by the BLS are too aggregated for our purposes, we construct our own measures using disaggregated import data from the Census Bureau. Our 6-digit NAICS industry-level import price index is a weighted average of the log change in import unit values (equal to import values divided by quantities) across all 10-digit Harmonized Tariff Schedule (HTS10)-country observations, h, c, within each NAICS industry i, where the weights are lagged annual import value weights

$$\Delta \ln(P_{it,imp}) = \sum_{h,c} w_{h,c,year-1} \Delta \ln(\text{import unit values}_{h,c,t}). \tag{30}$$

We construct a mapping between HTS10 codes and 6-digit NAICS industries throughout our sample period using the concordance by Pierce and Schott (2012).

Since we use industry-level data we do not have domestic competitors' prices within the same industry. Instead, we will estimate the size of the strategic complementarity effect using an industry's *foreign* competitors' prices. These are given by the import price index $P_{it,imp}$ constructed above. In contrast to the imported input price index, which is a weighted average of import prices across all industries that provide inputs to i, the competitors' price index is simply the import price index of industry i, e.g., the price of imported cars for the car industry.

The controls X_{it} include variables that pick up the composition of the industry's workforce in quarter t to address potential composition bias in an industry's wages. Specifically, we include the shares of prime-aged and older workers, the share of female workers, and the shares of workers with a high-school degree, associates degree, and bachelors degree or higher. We obtain these variables from the Census Bureau's Quarterly Workforce Indicators (QWI). Finally, δ_i is an industry fixed effect and ψ_t is a time fixed effect. The latter picks up any aggregate variation that affects all industries, such as changes in aggregate inflation expectations or general business cycle trends.

We provide some summary statistics on average four-quarter change in wages and input prices in our sample of industries in Table 3. The first two columns present statistics for industries in the "Goods" sector. To be consistent with the model, we define that sector to comprise all industries with positive imports in at least one year, i.e., there is some import competition. These industries are predominantly in manufacturing, with a few industries in agriculture and mining.[17] The last two columns present statistics for the "Services" sector, comprising all industries that are non-traded, mostly services. Import prices can still affect non-traded industries through imported intermediate inputs.

[17] Manufacturing accounted for about 63% of employment in goods-producing industries in the last decade.

Table 3: Summary Statistics

	Goods		Services	
Pre-Covid (2013:Q1 - 2019:Q4)	$\Delta\ln(P_{it,input})$	$\Delta\ln(Wage_{it})$	$\Delta\ln(P_{it,input})$	$\Delta\ln(Wage_{it})$
Mean	0.000	0.022	-0.006	0.028
P50	0.005	0.024	0.005	0.029
Mean of 4th quartile	0.063	0.079	0.078	0.073
Correlation	0.045		0.064	
COVID period (2020)				
Mean	-0.024	0.035	-0.066	0.050
P50	-0.015	0.029	-0.025	0.044
Mean of 4th quartile	0.028	0.116	0.004	0.127
Correlation	0.293		0.204	
COVID period (2021)				
Mean	0.149	0.049	0.171	0.060
P50	0.124	0.051	0.124	0.056
Mean of 4th quartile	0.300	0.128	0.387	0.147
Correlation	0.228		0.166	

The first panel presents statistics for the pre-COVID period. We find that the average industry's change in input prices is virtually zero in this period, with average wage growth between 2 and 3 percent. The correlation between wage growth and input price changes is also negligible prior to COVID. The second panel shows the same statistics for 2020. Input prices decline in that year, while wages exhibit slightly faster growth than in the earlier period. What stands out most, however, is the significantly higher correlation between wage and input price changes in 2020 compared to the pre-COVID period. The last panel shows the statistics for 2021. Both wages and input prices rise significantly, and moreover the growth is strongly correlated. Thus, what makes 2021 special is that it combines both high growth in wages and input prices with a strong correlation between the two.

We now estimate our regression specification (28) separately for goods and for services. Our regressions use Driscoll-Kraay standard errors with bandwidth two quarters to account for cross-sectional and time series correlation. We show that the combination of large input price changes and high correlation generates an amplified effect on producer prices.

6.2 Results

Table 4 shows the results from our baseline regressions for the goods sector, i.e., traded industries. Since different industries have different degrees of import penetration, we multiply the foreign competitors' price index, $P_{imp,it}$, by the industry's import share, s_i, in 2013. The first column presents the results from specification (28). We find a positive and significant correlation between producer prices and input costs for our sample period 2013-2021. A 10 percent increase in input prices is associated with a 3.1 percent rise in producer prices. We also find a positive pass-through from wages to producer prices, although the effect is small. A 10 percent increase in wages is associated with a 0.3 percent rise in producer prices. This small pass-through from wages to prices in the goods sector is consistent with earlier work (Heise et al. (2022)). The coefficient on the competitors' price index indicates that for an industry with the average import share of 31 percent, a 10 percent increase in import prices would lead to an increase in producer prices of 0.7 percent. Finally, productivity improvements have a negative impact on producer prices, as expected.

In column 2, we re-run this regression but interact the variables with a dummy for the year 2021. As shown before, inflation picked up significantly in 2021, and we have argued that simultaneous wage and input price changes lead to a stronger pass-through into producer prices. We find support for this hypothesis. Both wages and input prices have become more correlated with producer prices in 2021. In particular, a 10 percent rise in input prices was associated with a 2.4 percent rise in producer prices in the pre-2021 period, but led to a 4 percent increase in 2021. Even more strikingly, we find that the entire positive correlation between wage changes and producer prices is accounted for by 2021. While in earlier years the pass-through from wages to producer prices was insignificant, it rose to 12.6 percent in 2021. The correlation between producer prices and foreign competitors' prices has also strengthened. The pass-through of import prices into producer prices was around 5 percent in an industry with the average import share in the pre-2021 period, but rose to around 20 percent in 2021.

To test more directly whether the interaction between wages and input prices contributed to higher inflation, in column 3 we run the specification with additional non-linear marginal cost terms using (28). This specification includes an interaction term between wage changes and input prices changes, an interaction between productivity and input price changes, and squared wage and input price terms. We interact all terms with dummies for 2021 to examine structural changes in the coefficients. We find a positive and very significant effect of the product of wage and input price changes on producer prices in 2021. Moreover, once this term is included in the regression, the 2021 interaction terms on wages and input prices become insignificant. This result suggests that the interaction between wages and input prices can completely explain the pick-up in pass-through in 2021, corroborating our hypothesis.

The non-linear regression results indicate a positive interaction effect in 2021, but not in earlier years. As shown in Table 3, changes in wages and input prices were small until 2021, and the changes were virtually uncorrelated until 2020. This could explain the lack of an effect in prior years if smaller changes have a lower pass-through. As a robustness

Table 4: Pass Through for Goods, 2013:Q1 - 2021:Q3

	(1) $\Delta\ln(p_{it})$	(2) $\Delta\ln(p_{it})$	(3) $\Delta\ln(p_{it})$	(4) $\Delta\ln(p_{it})$
$\Delta\ln(p_{it,input})$	0.309***	0.236***	0.245***	0.284***
	(0.028)	(0.025)	(0.026)	(0.031)
$\Delta\ln(p_{it,input})$ × Year=20				-0.093**
				(0.035)
$\Delta\ln(p_{it,input})$ × Year=21		0.158***	0.046	-0.117
		(0.026)	(0.034)	(0.108)
$\Delta\ln(Wage_{it})$	0.029*	0.011	0.008	-0.004
	(0.016)	(0.013)	(0.011)	(0.012)
$\Delta\ln(Wage_{it})$ × Year=20				0.053*
				(0.028)
$\Delta\ln(Wage_{it})$ × Year=21		0.127***	-0.076	-0.044
		(0.023)	(0.046)	(0.038)
$s_i \times \Delta\ln(p_{it,imp})$	0.223***	0.174***	0.174***	0.158***
	(0.044)	(0.024)	(0.024)	(0.023)
$s_i \times \Delta\ln(p_{it,imp})$ × Year=20				0.098**
				(0.044)
$s_i \times \Delta\ln(p_{it,imp})$ × Year=21		0.477***	0.499***	0.504***
		(0.157)	(0.163)	(0.151)
$\Delta\ln(Wage_{it}) \times \Delta\ln(p_{it,input})$			-0.287	-0.414
			(0.237)	(0.312)
$\Delta\ln(Wage_{it}) \times \Delta\ln(p_{it,input})$ × Year=20				-0.320
				(0.476)
$\Delta\ln(Wage_{it}) \times \Delta\ln(p_{it,input})$ × Year=21			1.863***	1.951***
			(0.287)	(0.348)
$\Delta\ln(Wage_{it}) \times \Delta\ln(p_{it,input})$ × ×HH × Year=20				1.264**
				(0.611)
$\Delta\ln(A_{it})$	-0.154***	-0.150***	-0.149***	-0.140***
	(0.026)	(0.025)	(0.024)	(0.031)
Time Fixed Effects	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes
Worker Composition	Yes	Yes	Yes	Yes
Nonlinear Effects	No	No	Yes	Yes
R2	0.134	0.151	0.154	0.157
Observations	10038	10038	10038	10038

check, we next exploit the high correlation between wage and input price shocks in 2020, and construct dummies for whether an industry was in the top quartile of the wage change distribution and in the top quartile of the input price change distribution in that year. For industries that exhibited large changes in wages and input prices, we should pick up an interaction effect. Column 4 re-runs our non-linear specification with additional interactions for 2020, where the interaction between wages, input price changes, and the 2020 dummy is additionally interacted with a dummy for whether an industry was in the top quartile of both wage and input price change distribution. For this subset of industries we find a significant and positive interaction term, consistent with our hypothesis that both large and positively correlated shocks are needed.

In Appendix B, we perform several additional robustness checks of our findings. First, our structural equation (27) indicates that the effect of wages and productivity on prices should be of equal and opposite sign. We therefore run a constrained regression which imposes this requirement. Second, we introduce a proxy for domestic competitors, using the prices of the more aggregated 4-digit NAICS industry, to attempt to capture the competition that is missing from our baseline analysis. Third, we analyze whether our findings could be driven by a demand shock by re-running our regression with 3-digit NAICS industry by quarter fixed effects. This specification absorbs all factors that are common to the same 3-digit industry and quarter, and identifies our coefficients of interest from variation within broad industries. If demand shocks are common within 3-digit industries, then the remaining variation can be attributed to the shocks we focus on. The results in Appendix B indicate that our results continue to hold with these alternative specifications.

Table 5 shows analogous regressions for services. By definition, these industries are not directly affected by foreign competitors' prices and we therefore omit this control here. However, these industries can still be indirectly affected by imported input prices. Column 1 shows that there is a significant and positive correlation of both input prices and wages with producer prices. A 10 percent increase in input prices is associated with a 1 percent rise in producer prices on average. Similarly, a 10 percent rise in wages is associated with a 1.1 percent increase in prices. Column 2 shows that, in contrast to the goods sector, there was no increase in input price pass-through in 2021 for the services sector. However, the correlation between wages and prices rose significantly. A 10 percent rise in wages is associated with price growth of 0.7 percent in the earlier years, but with a 2.4 percent rise in prices in 2021. This rise in correlation between wages and producer prices is consistent with the model, since the substitution towards labor and domestically produced intermediates in particular in the goods sector drives up wages at the same time as prices rise.

The last column shows that the coefficient on the interaction between wages and input

Table 5: Pass Through for Services, 2013:Q1 - 2021:Q3

	(1) $\Delta \ln(p_{it})$	(2) $\Delta \ln(p_{it})$	(3) $\Delta \ln(p_{it})$
$\Delta \ln(p_{it,input})$	0.095***	0.094***	0.094***
	(0.011)	(0.016)	(0.015)
$\Delta \ln(p_{it,input}) \times$ Year=21		0.004	0.071*
		(0.026)	(0.037)
$\Delta \ln(Wage_{it})$	0.108***	0.069**	0.069**
	(0.034)	(0.029)	(0.031)
$\Delta \ln(Wage_{it}) \times$ Year=21		0.174***	0.358***
		(0.044)	(0.106)
$\Delta \ln(Wage_{it}) \times \Delta \ln(p_{it,input})$			-0.019
			(0.184)
$\Delta \ln(Wage_{it}) \times \Delta \ln(p_{it,input}) \times$ Year=21			-0.890***
			(0.277)
$\Delta \ln(A_{it})$	-0.030	-0.030	-0.029
	(0.019)	(0.018)	(0.018)
Time Fixed Effects	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes
Worker Composition	Yes	Yes	Yes
Nonlinear Effects	No	No	Yes
R2	0.046	0.050	0.055
Observations	5242	5242	5242

prices is actually *negative* in services in 2021. This absence of an amplification effect in services is consistent with the model, because the substitutability between labor and intermediates in services is low, and hence there is no change in substitution patterns when both labor and intermediates' costs rise. While we find a negative and significant effect on the interaction, we note that the interaction with the 2021 dummy also increases for both wages and input prices. From column 2, we know that the overall effect is to increase the correlation of wages with producer prices, while the correlation between intermediate input prices and producer prices stays unchanged.

7 Conclusion

In this paper, we have argued that a joint shock to wages and input prices can have an amplified effect on inflation by muting the substitution channel between the factors of production. Based on a calibrated New Keynesian DSGE model, we have shown that about one third of the recent pick-up in wage inflation could be attributed to the imported input price shock alone, as firms substitute away from imports towards domestic labor. Moreover, we find that the joint shock amplified price inflation by about 0.3 percentage points and wage inflation by about 0.3 percentage points relative to two separate shocks. Using disaggregated industry-level data, we provide empirical support for these predictions in the goods sector.

Our findings imply that the elasticity of inflation to shocks depends on the composition of shocks, and that in the recent period it might be higher than commonly assumed due to the amplification channel. A corollary of our findings is that if one of the shocks reverses, for example as supply chain bottlenecks ease, inflation might fall significantly as the substitution channel re-emerges.

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Appendix

A Theory

In this section we derive the main equations of the theoretical model in Section 3.

A.1 Households

A.1.1 Consumption-Savings Problem

Here, we derive the solution to the household consumption-savings problem. The first-order condition with respect to consumption implies

$$E_0 \beta^t (C_t - H_t)^{-\sigma} = \lambda_t P_{f,t}. \tag{31}$$

The first-order condition for assets is, for any state,

$$\lambda_t Q_{t+1} = \lambda_{t+1}, \tag{32}$$

which can be re-written as

$$\begin{aligned} \frac{\beta^t (C_t - H_t)^{-\sigma}}{P_t} Q_{t+1} &= \frac{\beta^{t+1} (C_{t+1} - H_{t+1})^{-\sigma}}{P_{f,t+1}} \\ Q_{t+1} &= \beta \frac{(C_{t+1} - H_{t+1})^{-\sigma}}{(C_t - H_t)^{-\sigma}} \frac{P_{f,t}}{P_{f,t+1}}. \end{aligned} \tag{33}$$

Taking expectations on both sides yields

$$E_t[Q_{t+1}] = \frac{1}{1+R_t} = \beta E_t \left[\frac{(C_{t+1} - H_{t+1})^{-\sigma}}{(C_t - H_t)^{-\sigma}} \frac{P_{f,t}}{P_{f,t+1}} \right], \tag{34}$$

which is the Euler equation. Rewriting H_t in terms of previous consumption

$$\frac{1}{1+R_t} = \beta E_t \left[\frac{(C_{t+1} - hC_t)^{-\sigma}}{(C_t - hC_{t-1})^{-\sigma}} \frac{P_{f,t}}{P_{f,t+1}} \right]. \tag{35}$$

A.1.2 Labor and Wage Setting

The labor bundler's problem is

$$\max_{\ell_t^s} \{ W_t^s L_t^s - \int_0^1 W_t^{s,\tau} \ell_t^{s,\tau} d\tau \}, \tag{36}$$

which implies the standard demand equation

$$\ell_t^{s,\tau} = \left(\frac{W_t^{s,\tau}}{W_t^s}\right)^{-\eta_t^s} L_t^s, \tag{37}$$

where

$$W_t^s = \left(\int_0^1 (W_t^{s,\tau})^{1-\eta_t^s}\right)^{1-\eta_t^s}. \tag{38}$$

Since the labor supply to each sector is additive, we can solve the wage setting problem separately for each sector. The wage setting problem for sector s is

$$\max_{W_t^{s,\tau}} E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \lambda^t W_t^{s,\tau} \ell_t^{s,\tau} - \frac{1}{1+\varphi} (\ell_t^{s,\tau})^{1+\varphi} - \frac{\psi_w}{2} \left(\frac{W_t^{s,\tau}}{W_{t-1}^{s,\tau}} - 1\right)^2 L_t^s \right\}, \tag{39}$$

where λ_t is the Lagrange multiplier from the general consumer problem representing the marginal utility of consumption. Plugging in for labor demand $\ell_t^{s,\tau}$ and using the expression for the Lagrange multiplier from (31) we get

$$\begin{aligned} \max_{W_t^{s,\tau}} E_0 \sum_{t=0}^{\infty} \beta^t \Bigg\{ & \frac{(C_t - hC_{t-1})^{-\sigma}}{P_{f,t}} (W_t^{s,\tau})^{1-\eta_t^s} (W_t^s)^{\eta_t^s} L_t^s \\ & - \frac{1}{1+\varphi} (W_t^{s,\tau})^{-\eta_t^s(1+\varphi)} (W_t^s)^{\eta_t^s(1+\varphi)} (L_t^s)^{1+\varphi} - \frac{\psi_w}{2} \left(\frac{W_t^{s,\tau}}{W_{t-1}^{s,\tau}} - 1\right)^2 L_t^s \Bigg\}. \end{aligned} \tag{40}$$

The first order condition of this problem is

$$\begin{aligned} (\eta_t^s - 1) \frac{(C_t - hC_{t-1})^{-\sigma}}{P_{f,t}} (W_t^{s,\tau})^{-\eta_t^s} (W_t^s)^{\eta_t^s} L_t^s &= \eta_t^s (W_t^{s,\tau})^{-\eta_t^s(1+\varphi)-1} (W_t^s)^{\eta_t^s(1+\varphi)} (L_t^s)^{1+\varphi} \\ - \psi_w \left(\frac{W_t^{s,\tau}}{W_{t-1}^{s,\tau}} - 1\right) \frac{1}{W_{t-1}^{s,\tau}} L_t^s &+ E_t \beta \psi_w \left(\frac{W_{t+1}^{s,\tau}}{W_t^{s,\tau}} - 1\right) \left(\frac{W_{t+1}^{s,\tau}}{W_t^{s,\tau}}\right) \frac{1}{W_t^{s,\tau}} L_t^s, \end{aligned} \tag{41}$$

Using that $W_t^{s,\tau} = W_t^s$ in equilibrium due to risk sharing, and using the real wage $w_t^s = W_t^s / P_{f,t}$, we obtain

$$(\eta_t^s - 1)(C_t - hC_{t-1})^{-\sigma} w_t^s L_t^s = \eta_t^s (L_t^s)^{1+\varphi} - \psi_w \pi_t^{s,w} (1 + \pi_t^{s,w}) L_t^s + E_t \beta \psi_w \pi_{t+1}^{s,w} (1 + \pi_{t+1}^{s,w}) L_t^s, \tag{42}$$

where $\pi_t^{s,w} = (1 + W_t^s / W_{t-1}^s)$. Rearranging, we obtain

$$(\eta_t^s - 1)(C_t - hC_{t-1})^{-\sigma} w_t^s = \eta_t^s (L_t^s)^{1+\varphi-1} - \psi_w \pi_t^{s,w} (1 + \pi_t^{s,w}) + E_t \beta \psi_w \pi_{t+1}^{s,w} (1 + \pi_{t+1}^{s,w}). \tag{43}$$

If there are no adjustment frictions, then the real wage is a markup over the ratio of the disutility of labor and the marginal utility of consumption.

A.2 Final Output Firm

Profit maximization within each sector implies demand for each differentiated product of

$$y^s_{f,t}(j) = \left(\frac{P^s_{f,t}(j)}{P^s_{f,t}}\right)^{-\theta} Y^s_{f,t}, \tag{44}$$

where the sectoral price index is

$$P^s_{f,t} = \left(\int_0^1 P^s_{f,t}(j)^{1-\theta} dj\right)^{\frac{1}{1-\theta}}. \tag{45}$$

Profit maximization across sectors yields the relative demand for each sector s aggregate

$$Y^s_{f,t} = \frac{\gamma^s}{\gamma^{s'}} \frac{P^{s'}_{f,t}}{P^s_{f,t}} Y^{s'}_{f,t}. \tag{46}$$

From the production function, $Y_{f,t} = (Y^M_{f,t})^{\gamma^M}(Y^S_{f,t})^{\gamma^S}$, we can substitute for $Y^S_{f,t}$ from (46) and solve for $Y^M_{f,t}$ as a function of total output:

$$Y_{f,t} = Y^M_{f,t}\left(\frac{\gamma^S}{\gamma^M}\right)^{\gamma^S}\left(\frac{P^M_{f,t}}{P^S_{f,t}}\right)^{\gamma^S}, \tag{47}$$

and hence

$$\begin{aligned} Y^M_{f,t} &= (\gamma^M)^{\gamma^S}(\gamma^S)^{-\gamma^S}(P^M_{f,t})^{-\gamma^S}(P^S_{f,t})^{\gamma^S} Y_t \\ &= (\gamma^M)^{1-\gamma^M}(\gamma^S)^{-\gamma^S}(P^M_{f,t})^{-\gamma^S}(P^s_{f,t})^{\gamma^S} Y_{f,t}. \end{aligned} \tag{48}$$

This expression gives the demand for the manufacturing output as a function of total final output.

The cost function of the final output firm is

$$C(Y_t) = P^M_{f,t}Y^M_{f,t} + P^S_{f,t}Y^S_{f,t}. \tag{49}$$

Plugging in for $Y^S_{f,t}$ from (46), we obtain

$$\begin{aligned} C(Y_t) &= P^M_{f,t} Y^M_{f,t} + \frac{\gamma^S}{\gamma^M} P^M_{f,t} Y^M_{f,t} \\ &= \frac{1}{\gamma^M} P^M_{f,t} Y^M_{f,t}. \end{aligned} \tag{50}$$

Plugging (48) into the cost function, we get

$$C(Y_{f,t}) = \left(\frac{1}{\gamma^M}\right)^{\gamma^M} \left(\frac{1}{\gamma^S}\right)^{\gamma^S} (P^M_{f,t})^{\gamma^M} (P^S_{f,t})^{\gamma^S} Y_{f,t}. \tag{51}$$

Therefore, we can define the aggregate price index as

$$P_{f,t} = \left(\frac{1}{\gamma^M}\right)^{\gamma^M} \left(\frac{1}{\gamma^S}\right)^{\gamma^S} (P^M_{f,t})^{\gamma^M} (P^S_{f,t})^{\gamma^S}. \tag{52}$$

We can obtain the aggregate inflation rate as a function of the sectoral inflation rates. Dividing (52) by $P_{f,t-1}$, we get

$$1 + \pi_t = (1 + \pi^M_t)^{\gamma^M} (1 + \pi^S_t)^{\gamma^S}, \tag{53}$$

where $\pi_t = (P_{f,t}/P_{f,t-1}) - 1$ is the inflation rate. Hence, aggregate inflation is a combination of inflation in the two sectors.

Finally, total spending in sector s is

$$\begin{aligned} P^s_{f,t} Y^s_{f,t} &= (\gamma^s)^{1-\gamma^s} (\gamma^{s'})^{-\gamma^{s'}} (P^s_{f,t})^{\gamma^s} (P^{s'}_{f,t})^{-\gamma^{s'}} Y_{f,t} \\ &= \gamma^s P_{f,t} Y_{f,t}. \end{aligned} \tag{54}$$

Therefore, demand for product j as a function of final output is

$$y^s_{f,t}(j) = \left(\frac{p^s_{f,t}(j)}{P^s_{f,t}}\right)^{-\theta} Y^s_{f,t} = \gamma^s \left(\frac{p^s_{f,t}(j)}{P^s_{f,t}}\right)^{-\theta} \left(\frac{P_{f,t}}{P^s_{f,t}}\right) Y_{f,t}. \tag{55}$$

A.3 Retailers

Retailers face producer prices $P^s_{x,t}(j,i)$ for their input from industry i. Cost minimization implies that retailers have demand for i of

$$x^s_t(j,i) = \left(\frac{P^s_{x,t}(j,i)}{P^s_{x,t}(j)}\right)^{-\nu} x^s_t(j), \tag{56}$$

where

$$P^s_{x,t}(j) = \left(\int_0^1 P^s_{x,t}(j,i)^{1-\nu} di\right)^{\frac{1}{1-\nu}} \tag{57}$$

is the producer price index faced by retailer j.

The retailers are monopolistic competitors, taking price indices as given, and face final demand from (7) of

$$y^s_{f,t}(j) = \gamma^s \left(\frac{P^s_{f,t}(j)}{P^s_{f,t}}\right)^{-\theta} \left(\frac{P_{f,t}}{P^s_{f,t}}\right) Y_{f,t}. \tag{58}$$

Retailers face a quadratic adjustment cost of $\frac{\psi_p}{2}(\frac{P^s_{f,t}(j)}{P^s_{f,t-1}(j)} - 1)^2 \gamma^s P_{f,t} Y_{f,t}$. Their real profits are

$$\begin{aligned} \Pi^s_t(j) = \gamma^s P^s_{f,t}(j)^{1-\theta}(P^s_{f,t})^{\theta-1} Y_{f,t} - p^s_{x,t}(j)\gamma^s P^s_{f,t}(j)^{-\theta}(P^s_{f,t})^{\theta-1} P_{f,t} Y_{f,t} \\ - \frac{\psi_p}{2}\left(\frac{P^s_{f,t}(j)}{P^s_{f,t-1}(j)} - 1\right)^2 \gamma^s Y_{f,t}, \end{aligned} \tag{59}$$

where $p^s_{x,t}(j) \equiv P^s_{x,t}(j)/P_{f,t}$ are real marginal costs. The firms' maximization problem is

$$\begin{aligned} \max_{P^s_{f,t+k}(j)} E_t\Bigg\{\sum_{k=0}^{\infty} \beta^k \left(\frac{U'(C_{t+k})}{U'(C_t)}\right) \Bigg[\left(\frac{P^s_{f,t+k}(j)}{P^s_{f,t+k}} - p^s_{x,t+k}(j)\frac{P_{f,t+k}}{P^s_{f,t+k}}\right)\gamma^s P^s_{f,t+k}(j)^{-\theta}(P^s_{f,t+k})^{\theta} Y_{f,t+k} \\ - \frac{\psi_p}{2}\left(\frac{P^s_{f,t+k}(j)}{P^s_{f,t+k-1}(j)} - 1\right)^2 \gamma^s Y_{f,t+k}\Bigg]\Bigg\}. \end{aligned} \tag{60}$$

Under the assumption that all retailers are symmetric, the solution to the maximization problem is

$$\begin{aligned} (\theta-1)\frac{Y_{f,t}}{P^s_{f,t}} = \theta p^s_{x,t}\left(\frac{P_{f,t}}{P^s_{f,t}}\right)\frac{Y_{f,t}}{P^s_{f,t}} - \psi_p\left(\frac{P^s_{f,t}}{P^s_{f,t-1}} - 1\right)\frac{1}{P^s_{f,t-1}} Y_{f,t} \\ + \beta\psi_p E_t\left[\frac{(C_{t+1}-H_{t+1})^{-\sigma}}{(C_t - H_t)^{-\sigma}}\left(\frac{P^s_{f,t+1}}{P^s_{f,t}} - 1\right)\left(\frac{P^s_{f,t+1}}{P^s_{f,t}}\right)\frac{1}{P^s_{f,t}} Y_{f,t+1}\right], \end{aligned} \tag{61}$$

which becomes

$$(\theta-1) = \theta\frac{p^s_{x,t}}{p^s_{f,t}} - \psi(1+\pi^s_t)\pi^s_t + \beta\psi E_t\left[\frac{(C_{t+1}-hC_t)^{-\sigma}}{(C_t - hC_{t-1})^{-\sigma}}\frac{Y_{f,t+1}}{Y_{f,t}}(1+\pi^s_{t+1})\pi^s_{t+1}\right], \tag{62}$$

where $\pi^s_t = P^s_{f,t}/P^s_{f,t-1} - 1$, and $p^s_{f,t} = P^s_{f,t}/P_{f,t}$.

A.4 Intermediate Goods Firms

A.4.1 Firm and Industry Demand

In this section, we derive the demand faced by producer k. Given price $P^s_{x,t}(j,i,k)$, the first order condition for demand of the firm's output is

$$(N^s_t)^{\frac{1}{1-\mu}} x^s_t(j,i,k)^{-\frac{1}{\mu}} \left(\sum_{k=1}^{N^s_D} x^s_t(j,i,k)^{\frac{\mu-1}{\mu}} + \sum_{k=1}^{N^s_F} x^s_t(j,i,k)^{\frac{\mu-1}{\mu}} \right)^{\frac{\mu}{\mu-1}-1} = P^s_{x,t}(j,i,k), \tag{63}$$

implying

$$x^s_t(j,i,k) = \left(\frac{P^s_{x,t}(j,i,k)}{P^s_{x,t}(j,i,k')} \right)^{-\mu} x^s_t(j,i,k'). \tag{64}$$

Plugging into the aggregator function and re-arranging, we get

$$x^s_t(j,i,k) = (N^s_t)^{\frac{\mu}{\mu-1}} \left(\sum_{k=1}^{N^s_D} P^s_{x,t}(j,i,k)^{1-\mu} + \sum_{k=1}^{N^s_F} P^s_{x,t}(j,i,k)^{1-\mu} \right)^{\frac{\mu}{1-\mu}} P^s_{x,t}(j,i,k)^{-\mu} \frac{x^s_t(j,i)}{N^s}. \tag{65}$$

Thus, the demand faced by firm k is

$$x^s_t(j,i,k) = \left(\frac{P^s_{x,t}(j,i,k)}{P^s_{x,t}(j,i)} \right)^{-\mu} \frac{x^s_t(j,i)}{N^s}, \tag{66}$$

where

$$P^s_{x,t}(j,i) = (N^s_t)^{\frac{1}{\mu-1}} \left(\sum_{k=1}^{N^s_D} P^s_{x,t}(j,i,k)^{1-\mu} + \sum_{k=1}^{N^s_F} P^s_{x,t}(j,i,k)^{1-\mu} \right)^{\frac{1}{1-\mu}}, \tag{67}$$

and $P^s_{x,t}(j,i,k) = P^s_{x,t}(j,i) = P^s_{x,t}(j)$ in a completely symmetric equilibrium.

A.4.2 Roundabout Production Technology

In this section, we describe the roundabout production technology and derive the sectoral demand for domestic intermediates.

The domestic inputs are assembled using all industries' output via a roundabout production technology. The domestic input aggregate $Z^s_t(j,i,k)$ used by firm k in industry i for retailer j in sector s combines inputs from the manufacturing and service sector according to

$$Z^s_t(j,i,k) = (Z^{s,M}_t(j,i,k))^{\gamma_M} (Z^{s,S}_t(j,i,k))^{\gamma_S}. \tag{68}$$

The sectoral aggregates are in turn combined from all industries using

$$Z_t^{s,s'}(j,i,k) = \left[\int_0^1 z_t^{s,s'}(j,i,k,i')^{\frac{\nu-1}{\nu}} di'\right]^{\frac{\nu}{\nu-1}}, \tag{69}$$

where $z_t^{s,s'}(j,i,k,i')$ is the output from intermediate industry i' in sector s' used as input by firm k in industry i in sector s. This output is produced by firms k' in industry i' according to

$$z_t^{s,s'}(j,i,k,i') = (N_t^s)^{\frac{1}{1-\mu}} \left(\sum_{k=1}^{N_D^s} x_t^s(j,i,k,i',k')^{\frac{\mu-1}{\mu}} + \sum_{k=1}^{N_F^s} x_t^s(j,i,k,i',k')^{\frac{\mu-1}{\mu}}\right)^{\frac{\mu}{\mu-1}}. \tag{70}$$

The demand for producer (k')'s output by industry i' for use as intermediate is, as shown in Appendix A.4.1 for the consumer side

$$z_t^{s,s'}(j,i,k,i',k') = \left(\frac{P_{x,t}^{s'}(j,i',k')}{P_{x,t}^{s'}(j,i')}\right)^{-\mu} \frac{z_t^{s,s'}(j,i,k,i')}{N_t^s}, \tag{71}$$

where $P_{x,t}^{s'}(j,i',k')$ is the price charged by firm k'.

The demand for industry i' as input for firm k in industry i in sector s for retailer j is obtained from cost minimization as

$$z_t^{s,s'}(j,i,k,i') = \left(\frac{P_{x,t}^{s'}(j,i')}{P_{x,t}^{s'}(j)}\right)^{-\nu} Z_t^{s,s'}(j,i,k), \tag{72}$$

similar to the demand from retailers derived in (56), where $P_{x,t}^{s'}$ is as before the producer price index. For the choice of inputs by sector, we have

$$Z_t^{s,s'}(j,i,k) = \gamma^{s,s'} \left(\frac{P_{x,dom,t}^s}{P_{x,t}^{s'}}\right) Z_t^s(j,i,k), \tag{73}$$

where

$$P_{x,dom,t} = \left(\frac{1}{\gamma^M}\right)^{\gamma^M} \left(\frac{1}{\gamma^S}\right)^{\gamma^S} (P_{x,t}^M)^{\gamma^M} (P_{x,t}^S)^{\gamma^S} \tag{74}$$

is the domestic input price index.

A.4.3 Producers' Marginal Costs

Cost minimization across domestic and foreign intermediates implies

$$M_t^s(j,i,k) = Z_t^s(j,i,k)\left(\frac{P_{x,imp,t}}{P_{x,dom,t}^s}\right)^{-\xi}. \tag{75}$$

Plugging this into the CES aggregator for domestic and foreign inputs, equation (15), yields

$$D_t^s(j,i,k) = Z_t^s(j,i,k)(P_{x,input,t}^s)^{-\xi}(P_{x,dom,t}^s)^{\xi}, \tag{76}$$

where

$$P_{x,input,t}^s = [(P_{x,dom,t}^s)^{1-\xi} + (P_{x,imp,t})^{1-\xi}]^{\frac{1}{1-\xi}} \tag{77}$$

is the input price index. It follows that

$$Z_t^s(j,i,k) = \left(\frac{P_{x,dom,t}^s}{P_{x,input,t}^s}\right)^{-\xi} D_t^s(j,i,k) \tag{78}$$

and

$$M_t^s(j,i,k) = \left(\frac{P_{x,imp,t}}{P_{x,input,t}^s}\right)^{-\xi} D_t^s(j,i,k). \tag{79}$$

The expenditure share on imported inputs is

$$\frac{P_{x,imp,t}M_t^s(j,i,k)}{P_{x,input,t}^s D_t^s(j,i,k)} = \frac{(P_{x,imp,t})^{1-\xi}}{(P_{x,input,t}^s)^{1-\xi}} = \frac{(P_{x,imp,t})^{1-\xi}}{(P_{x,dom,t}^s)^{1-\xi} + (P_{x,imp,t})^{1-\xi}} \equiv \alpha_s, \tag{80}$$

where α_s is the import share in sector s.

Cost minimization across labor and intermediates implies

$$L_t^s(j,i,k) = \frac{1}{\Lambda_s} A_t^{\rho_s-1} D_t^s(j,i,k)\left(\frac{W_t^s}{P_{x,input,t}^s}\right)^{-\rho_s}. \tag{81}$$

Plugging this into the CES aggregator for labor and intermediates, equation (14), yields

$$x_t^s(j,i,k) = \frac{1}{\Lambda_s} D_t(j,i,k)(P_{x,input,t}^s)^{\rho_s}(MC_{D,t}^s)^{-\rho_s}, \tag{82}$$

where

$$MC_{D,t}^s = \left[\left(\frac{W_t^s}{A_t}\right)^{1-\rho_s} + \Lambda_s(P_{x,input,t}^s)^{1-\rho_s}\right]^{\frac{1}{1-\rho_s}}. \tag{83}$$

It follows that the demand for the intermediate good is

$$D_t^s(j,i,k) = \Lambda_s \left(\frac{P_{x,input,t}^s}{MC_{D,t}^s} \right)^{-\rho_s} x_t^s(j,i,k). \tag{84}$$

Similarly, the demand for labor is

$$L_t^s(j,i,k) = A_t^{\rho_s - 1} \left(\frac{W_t^s}{MC_{D,t}^s} \right)^{-\rho_s} x_t^s(j,i,k). \tag{85}$$

Plugging these two expressions into the firm's cost function yields

$$\begin{aligned} C(x_t^s(j,i,k)) &= W_t L_t^s(j,i,k) + P_{x,input,t}^s D_t^s(j,i,k) \\ &= MC_{D,t}^s(x_t^s(j,i,k)). \end{aligned} \tag{86}$$

Thus, $MC_{D,t}^s$ are the firm's marginal costs.

The share of labor in total costs is

$$\begin{aligned} \lambda_t^s &= \frac{A_t^{\rho_s-1}(W_t^s)^{1-\rho_s} MC_{D,t}^{\rho_s}(x_t^s(j,i,k))}{A_t^{\rho_s-1}(W_t^s)^{1-\rho_s} MC_{D,t}^{\rho_s}(x_t^s(j,i,k)) + \Lambda_s(P_{x,input,t}^s)^{1-\rho_s} MC_{D,t}^{\rho_s}(x_t^s(j,i,k))} \\ &= \frac{(W_t^s/A_t)^{1-\rho_s}}{(W_t^s/A_t)^{1-\rho_s} + \Lambda_s(P_{x,input,t}^s)^{1-\rho_s}}. \end{aligned} \tag{87}$$

This equation links the parameter Λ_s to the labor share in steady state, λ^s.

A.4.4 Price Setting Problem

In this section we find the solution for the firm's profit maximization problem. We first derive the firms' effective elasticity of demand. We then solve the profit maximization problem and obtain firms' prices.

Demand Elasticity

Each producer faces final demand as well as demand for its output as inputs into other industries. Each retailer also demands some output $\gamma^s \frac{\psi}{2}(\pi_t^s)^2 Y_{f,t}$ to cover its price adjustment cost. From the demand equation (12), each producer thus faces total demand of

$$x^s_{tot,t}(j,i,k) = \frac{1}{N^s}\left(\frac{P^s_{x,t}(j,i,k)}{P^s_{x,t}(j,i)}\right)^{-\mu}\left(\frac{P^s_{x,t}(j,i)}{P^s_{x,t}(j)}\right)^{-\nu} \times \left(x^s_t(j) + \int_0^1 \sum_{k'} Z^{s,s}_t(j,i',k')di' + \int_0^1 \sum_{k'} Z^{s',s}_t(j,i',k')di'\right), \tag{88}$$

where the first term is the demand by the associated retailer, which includes additionally the resources needed for price changes, and the second and third terms are the demands for inputs by all other firms in all other industries to produce for the retailer. We denote by $Z^s_t(j) \equiv \int_0^1 \sum_{k'} Z^s_t(j,i',k')di'$ the demand by retailer j in sector s for inputs to obtain

$$x^s_{tot,t}(j,i,k) = \frac{1}{N^s}\left(\frac{P^s_{x,t}(j,i,k)}{P^s_{x,t}(j,i)}\right)^{-\mu}\left(\frac{P^s_{x,t}(j,i)}{P^s_{x,t}(j)}\right)^{-\nu}\left(\gamma^s\left(\frac{P^s_{f,t}(j)}{P^s_{f,t}}\right)^{-\theta}\left(\frac{P_{f,t}}{P^s_{f,t}}\right)Y_{f,t} + \gamma^s\frac{\psi_p}{2}(\pi^s_t)^2 Y_{f,t} + \gamma^s\left(\frac{P^s_{x,dom,t}}{P^s_{x,t}}\right)Z^s_t(j) + \gamma^s\left(\frac{P^{s'}_{x,dom,t}}{P^s_{x,t}}\right)Z^{s'}_t(j)\right). \tag{89}$$

Each producer therefore faces an effective elasticity of demand of

$$\mathcal{E}^s_t(j,i,k) \equiv -\frac{d\log x^s_{tot,t}(j,i,k)}{d\log P^s_{x,t}(j,i,k)} = \mu - (\mu-\nu)\frac{\partial \log P^s_{x,t}(j,i)}{\partial \log P^s_{x,t}(j,i,k)}. \tag{90}$$

From the definition of an industry's price index (13), we have that

$$\frac{\partial \log P^s_{x,t}(j,i)}{\partial \log P^s_{x,t}(j,i,k)} = \frac{P^s_{x,t}(j,i,k)^{1-\mu}}{\sum_{k=1}^{N^s_D} P^s_{x,t}(j,i,k)^{1-\mu} + \sum_{k=1}^{N^s_F} P^s_{x,t}(j,i,k)^{1-\mu}}. \tag{91}$$

We can define a firm's market share as

$$S^s_t(j,i,k) \equiv \frac{P^s_{x,t}(j,i,k)x^s_{tot,t}(j,i,k)}{\sum_{k'=1}^{N^s_D} P^s_{x,t}(j,i,k')x^s_{tot,t}(j,i,k') + \sum_{k'=1}^{N^s_F} P^s_{x,t}(j,i,k')x^s_{tot,t}(j,i,k')} = \left(\frac{1}{N^s}\right)\frac{P^s_{x,t}(j,i,k)^{1-\mu}}{P^s_{x,t}(j,i)^{1-\mu}}. \tag{92}$$

Using this expression, we can re-express the demand elasticity as

$$\mathcal{E}^s_t(j,i,k) = \mu - (\mu-\nu)S^s_t(j,i,k) = \mu(1 - S^s_t(j,i,k)) + \nu S^s_t(j,i,k). \tag{93}$$

Thus, the firm's demand elasticity is a weighted average of the within-industry and across-industry elasticities of substitution.

Prices

Producer k in industry i in sector s sets prices $P^s_{x,t}(j,i,k)$ to solve

$$\max_{P^s_{x,t}(j,i,k)} [P^s_{x,t}(j,i,k) - MC^s_{D,t}]x^s_{tot,t}(j,i,k), \tag{94}$$

where $x^s_{tot,t}(j,i,k)$ is given by (89). The first-order condition of this problem is

$$\begin{aligned} &[(1-\mu)P^s_{x,t}(j,i,k)^{-\mu} + \mu P_{x,t}(j,i,k)^{-\mu-1}MC^s_{D,t}]P^s_{x,t}(j,i)^{\mu-\nu}P^s_{x,t}(j)^{\nu} \\ &+ \left[(\mu-\nu)P^s_{x,t}(j,i,k)^{-\mu}P^s_{x,t}(j,i)^{\mu-\nu-1}P^s_{x,t}(j)^{\nu}\frac{\partial P^s_{x,t}(j,i)}{\partial P^s_{x,t}(j,i,k)}\right][P^s_{x,t}(j,i,k) - MC^s_{D,t}] = 0. \end{aligned} \tag{95}$$

The derivative of the price index is equal to

$$\frac{\partial P^s_{x,t}(j,i)}{\partial P^s_{x,t}(j,i,k)} = \left(\frac{1}{N^s}\right)\left(\frac{P^s_{x,t}(j,i,k)}{P^s_{x,t}(j,i)}\right)^{-\mu} = S^s_t(j,i,k) \tag{96}$$

where we have used equation (91) and the expression for the market share (92). Plugging in, the first-order condition becomes

$$(1-\mu)P^s_{x,t}(j,i,k) + \mu MC^s_{D,t} + (\mu-\nu)S^s_t(j,i,k)[P^s_{x,t}(j,i,k) - MC^s_{D,t}] = 0, \tag{97}$$

which can be rearranged to

$$P^s_{x,t}(j,i,k) = \frac{\mu - (\mu-\nu)S^s_t(j,i,k)}{(\mu-1) - (\mu-\nu)S^s_t(j,i,k)}MC^s_{D,t}. \tag{98}$$

Using the definition of the demand elasticity, the producer price is thus

$$P^s_{x,t}(j,i,k) = \frac{\mathcal{E}^s_t(j,i,k)}{\mathcal{E}^s_t(j,i,k) - 1}MC^s_{D,t}, \tag{99}$$

which can be re-written with real marginal costs by dividing both sides by $P_{f,t}$.

A.5 Aggregation

In this section we derive the aggregate resource constraints. Using equation (89) and symmetry of producers of the same origin, each domestic producer supplying retailer j faces total demand of

$$x^s_{tot,t}(j,i,k) = \frac{1}{N^s}\left(\frac{P^s_{D,x,t}}{P^s_{x,t}}\right)^{-\mu}\left(\gamma^s\left(\frac{P_{f,t}}{P^s_{f,t}}\right)Y_{f,t}\right.$$
$$\left.+\gamma^s\frac{\psi_p}{2}(\pi^s_t)^2Y_{f,t}+\gamma^s\left(\frac{P^s_{x,dom,t}}{P^s_{x,t}}\right)Z^s_t(j)+\gamma^s\left(\frac{P^{s'}_{x,dom,t}}{P^s_{x,t}}\right)Z^{s'}_t(j)\right).$$

We aggregate across domestic producers and integrate across industries and retailers, and use $Y_{f,t} = C_t$, to get total output in sector s:

$$Y^s_t = \frac{N^s_D}{N^s}\left(\frac{P_{D,x,t}}{P_{x,t}}\right)^{-\mu}\left(\gamma^s\left(\frac{P_{f,t}}{P^s_{f,t}}\right)C_t+\gamma^s\frac{\psi_p}{2}(\pi^s_t)^2C_t+\gamma^s\left(\frac{P^s_{x,dom,t}}{P^s_{x,t}}\right)Z^s_t+\gamma^s\left(\frac{P^{s'}_{x,dom,t}}{P^s_{x,t}}\right)Z^{s'}_t\right).$$

The demand for intermediates by firm k can be derived as

$$Z^s_t(j,i,k) = \left(\frac{P^s_{x,dom,t}}{P^s_{x,input,t}}\right)^{-\xi}D^s_t(j,i,k)$$
$$= \Lambda_s\left(\frac{P^s_{x,dom,t}}{P^s_{x,input,t}}\right)^{-\xi}\left(\frac{P^s_{x,input,t}}{MC^s_{D,t}}\right)^{-\rho_s}x^s_{tot,t}(j,i,k).$$

Since only domestic firms demand domestic intermediates, we can obtain the total domestic demand in sector s by summing across domestic firms and using symmetry to obtain

$$Z^s_t = \Lambda_s\left(\frac{P^s_{x,dom,t}}{P^s_{x,input,t}}\right)^{-\xi}\left(\frac{P^s_{x,input,t}}{MC^s_{D,t}}\right)^{-\rho_s}Y^s_t.$$

The total demand for labor by firm k is, from (85),

$$L^s_t(j,i,k) = A^{\rho_s-1}_t\left(\frac{W^s_t}{MC^s_{D,t}}\right)^{-\rho_s}x^s_{tot,t}(j,i,k).$$

Aggregating across firms, industries, and retailers, we obtain

$$L^s_t = A^{\rho_s-1}_t\left(\frac{W^s_t}{MC^s_{D,t}}\right)^{-\rho_s}Y^s_t.$$

A.6 Equilibrium Conditions

Our equilibrium consists of 40 endogenous variables: C_t, Z^M_t, Z^S_t, π_t, π^M_t, π^S_t, $\pi^{M,w}_t$, $\pi^{S,w}_t$, p^M_f, p^S_f, $p^M_{x,t}$, $p^S_{x,t}$, $p^M_{D,x,t}$, $p^S_{D,x,t}$, $p^M_{F,x,t}$, $p^S_{F,x,t}$, $MC^M_{D,t}$, $MC^S_{D,t}$, $MC^M_{F,t}$, $MC^S_{F,t}$, $p^M_{x,input,t}$, $p^S_{x,input,t}$,

$p_{x,imp,t}$, $p^M_{x,dom,t}$, $p^S_{x,dom,t}$, w^M_t, w^S_t, L^M_t, L^S_t, Y_t, Y^M_t, Y^S_t, A_t, η^M_t, η^S_t, R_t, S^M_D, S^S_D, S^M_F, and S^S_F.

We have the following conditions that describe the system:

1. Euler equation:

$$(C_t - hC_{t-1})^{-\sigma} = \beta E_t \left[\frac{1+R_t}{1+\pi_{t+1}} (C_{t+1} - hC_t)^{-\sigma} \right] \tag{100}$$

2. Demand for domestic intermediates:

$$Z^s_t = \Lambda_s (p^s_{x,dom,t})^{-\xi} (p^s_{x,input,t})^{\xi-\rho_s} (MC^s_{D,t})^{\rho_s} Y^s_t \tag{101}$$

3. Aggregate inflation:

$$1 + \pi_t = (1 + \pi^M_t)^{\gamma^M} (1 + \pi^S_t)^{\gamma^S} \tag{102}$$

4. Sectoral inflation:

$$(\theta - 1) = \theta \frac{p^s_{x,t}}{p^s_{f,t}} - \psi_p (1 + \pi^s_t)\pi^s_t + \beta \psi_p E_t \left[\frac{(C_{t+1} - hC_t)^{-\sigma}}{(C_t - hC_{t-1})^{-\sigma}} \frac{C_{t+1}}{C_t} (1 + \pi^s_{t+1}) \pi^s_{t+1} \right] \tag{103}$$

5. Sectoral wage inflation:

$$1 + \pi^{s,w}_t = \frac{w^s_t}{w^s_{t-1}} (1 + \pi_t) \tag{104}$$

6. Retailers' real marginal costs

$$p^s_{x,t} = (N^s_t)^{\frac{1}{\mu-1}} \left(N^s_{D,t} (p^s_{D,x,t})^{1-\mu} + N^s_{F,t} (p^s_{F,x,t})^{1-\mu} \right)^{\frac{1}{1-\mu}} \tag{105}$$

7. Domestic manufacturer's price

$$p^s_{D,x,t} = \frac{\mu - (\mu - \nu) S^s_D}{(\mu - 1) - (\mu - \nu) S^s_D} MC^s_{D,t} \tag{106}$$

8. Foreign manufacturer's price

$$p^s_{F,x,t} = \frac{\mu - (\mu - \nu) S^s_F}{(\mu - 1) - (\mu - \nu) S^s_F} MC^s_{F,t} \tag{107}$$

9. Domestic producers' real marginal costs:

$$MC^s_{D,t} = \left[\left(\frac{w^s_t}{A_t} \right)^{1-\rho_s} + \Lambda_s (p^s_{x,input,t})^{1-\rho_s} \right]^{\frac{1}{1-\rho_s}} \tag{108}$$

10. Foreign producers' real marginal costs:

$$ln(MC^s_{F,t+1}) = (1-\gamma_p) ln(MC^s_F) + \gamma_p ln(MC^s_{F,t}) + \epsilon^P_{t+1} \tag{109}$$

11. Real input price index:

$$p^s_{x,input,t} = \left[(p^s_{x,dom,t})^{1-\xi} + (p_{x,imp,t})^{1-\xi} \right]^{\frac{1}{1-\xi}} \tag{110}$$

12. Real domestic input price index:

$$p^s_{x,dom,t} = \left(\frac{1}{\gamma^{s,M}} \right)^{\gamma^{s,M}} \left(\frac{1}{\gamma^{s,S}} \right)^{\gamma^{s,S}} (p^M_{x,t})^{\gamma^{s,M}} (p^S_{x,t})^{\gamma^{s,S}} \tag{111}$$

13. Sectoral prices:

$$p^s_t = p^s_{t-1} \frac{1+\pi^s_t}{1+\pi_t} \tag{112}$$

14. Sectoral labor supply:

$$\begin{aligned} &(\eta^s_t - 1)(C_t - hC_{t-1})^{-\sigma} w^s_t = \\ &\qquad \eta^s_t (L^s_t)^{\gamma_s(1+\varphi)-1} - \psi_w \pi^{s,w}_t (1+\pi^{s,w}_t) + \beta \psi_w E_t \pi^{s,w}_{t+1} (1+\pi^{s,w}_{t+1}) \end{aligned} \tag{113}$$

15. Sectoral labor demand

$$L^s_t = A^{\rho_s - 1}_t \left(\frac{w^s_t}{MC^s_{D,t}} \right)^{-\rho_s} Y^s_t \tag{114}$$

16. Sectoral goods market clearing:

$$\begin{aligned} Y^s_t = \frac{N^s_{D,t}}{N^s_t} \left(\frac{P_{D,x,t}}{P_{x,t}} \right)^{-\mu} \Bigg(&\gamma^s \left(\frac{1}{p^s_t} \right) C_t \\ &+ \gamma^s \frac{\psi}{2} (\pi^s_t)^2 C_t + \gamma^{s,s} \left(\frac{p^s_{x,dom,t}}{p^s_{x,t}} \right) Z^s_t + \gamma^{s',s} \left(\frac{p^{s'}_{x,dom,t}}{p^s_{x,t}} \right) Z^{s'}_t \Bigg) \end{aligned} \tag{115}$$

17. Aggregate goods market clearing:

$$Y_t = Y_t^M + Y_t^S \tag{116}$$

18. Domestic firm market shares:

$$S_D^s = \left(\frac{1}{N_t^s}\right) \frac{(p_{D,x,t}^s)^{1-\mu}}{(p_{x,t}^s)^{1-\mu}} \tag{117}$$

19. Foreign firm market shares:

$$S_F^s = \left(\frac{1}{N_t^s}\right) \frac{(p_{F,x,t}^s)^{1-\mu}}{(p_{x,t}^s)^{1-\mu}} \tag{118}$$

20. Technology process:

$$ln(A_{t+1}) = \gamma_A ln(A_t) + \epsilon_{t+1}^A \tag{119}$$

21. Real imported input price process:

$$ln(p_{x,imp,t+1}) = (1 - \gamma_P) ln(p_{imp}) + \gamma_P ln(p_{x,imp,t}) + \epsilon_{t+1}^P \tag{120}$$

22. Wage shocks:

$$\eta_{t+1}^s = (1 - \gamma_\eta)\eta^s + \gamma_\eta \eta_t^s + \epsilon_{t+1}^{\eta,s} \tag{121}$$

23. Monetary policy:

$$R_t = \varrho R_{t-1} + (1 - \varrho)R + (1 - \varrho)\Bigg(\phi_\pi \pi_t + \phi_y (ln(Y_t) - ln(Y))\Bigg) + \epsilon_t^M \tag{122}$$

A.7 Price Change Equation

The change in the markup, $d\ln \mathcal{M}_t(j,i,k)$ is given by

$$\begin{aligned}
d\ln \mathcal{M}_t(j,i,k) &= d\ln\left[\mu-(\mu-\nu)S_t^s(j,i,k)\right] - d\ln\left[(\mu-1)-(\mu-\mu)S_t^s(j,i,k)\right] \\
&= \left[-\frac{\mu-\nu}{\mu-(\mu-\nu)S_t^s(j,i,k)} + \frac{\mu-\nu}{(\mu-1)-(\mu-\nu)S_t^s(j,i,k)}\right] \\
&\times \frac{\partial S_t^s(j,i,k)}{\partial \log S_t^s(j,i,k)} d\ln S_t^s(j,i,k) \\
&= \frac{(\mu-\nu)S_t^s(j,i,k)}{\left[\mu-(\mu-\nu)S_t^s(j,i,k)\right]\left[(\mu-1)-(\mu-\nu)S_t^s(j,i,k)\right]} \\
&\times \left[(1-\mu)d\ln P_{x,t}^s(j,i,k) - (1-\mu)d\ln P_{x,t}^s(j,i)\right] \\
&= \frac{S_t^s(j,i,k)}{\left[\frac{\mu}{\mu-\nu} - S_t^s(j,i,k)\right]\left[1-\frac{\mu-\nu}{\mu-1}S_t^s(j,i,k)\right]}\left[d\ln P_{x,t}^s(j,i) - d\ln P_{x,t}^s(j,i,k)\right] \\
&= -\Gamma_t(j,i,k)\left[d\ln P_{x,t}^s(j,i,k) - d\ln P_{x,t}^s(j,i)\right],
\end{aligned}$$

where $\Gamma_t(j,i,k) = -(\partial \ln \mathcal{M}_t(j,i,k)/\partial \ln P_{x,t}^s(j,i,k)) \geq 0$ is the elasticity of the markup with respect to a firm's own price. From

$$\Gamma_t(j,i,k) = \frac{S_t^s(j,i,k)}{\left[\frac{\mu}{\mu-\nu} - S_t^s(j,i,k)\right]\left[1-\frac{\mu-\nu}{\mu-1}S_t^s(j,i,k)\right]}, \tag{123}$$

it follows that $\Gamma_t(j,i,k) = 0$ if $S_t^s(j,i,k) = 0$.

Finally, the derivative of the markup elasticity with respect to the market share $S(i,j)$ is given by

$$\frac{d\Gamma_t(j,i,k)}{dS_t^s(j,i,k)} = $$
$$\frac{\left[\frac{\mu}{\mu-\nu} - S_t^s(j,i,k)\right]\left[1-\frac{\mu-\nu}{\mu-1}S_t^s(j,i,k)\right] + \left[1-\frac{\mu-\nu}{\mu-1}S_t^s(j,i,k)\right] + \frac{\mu-\nu}{\mu-1}\left[\frac{\mu}{\mu-\nu} - S_t^s(j,i,k)\right]}{\left\{\left[\frac{\mu}{\mu-\nu} - S^{t(j,i,k)}\right]\left[1-\frac{\mu-\nu}{\mu-1}S(i,j)\right]\right\}^2} > 0.$$

B Additional Empirical Results

In this section, we show additional regression results to explore the robustness of our baseline specification (28) in the goods sector.

B.1 Constrained Regression

One concern with our findings in the main text is that we did not impose the restriction that the coefficient on the wage and the coefficient on labor productivity are of equal and opposite signs, as implied by the theory. We therefore re-run our baseline regression (28), but impose the restriction $\beta_1 + \beta_2 = 0$. The results, in column 1 of Table A.1, are similar to those in the main text. In the second column, we additionally include interactions with 2021. We also interact productivity with a 2021 dummy, and impose the additional constraint that the coefficients on the wage and productivity terms interacted with 2021 are of equal and opposite signs. We still find that the correlation of wages with prices increases in 2021, as in the baseline.

Table A.1: Pass Through for Traded Industries with Constraints, 2013:Q1 - 2021:Q3

	(1) $\Delta\ln(p_{it})$	(2) $\Delta\ln(p_{it})$
$\Delta\ln(p_{it,input})$	0.315***	0.241***
	(0.023)	(0.018)
$\Delta\ln(p_{it,input}) \times$ Year=21		0.144***
		(0.055)
$\Delta\ln(Wage_{it})$	0.095***	0.079***
	(0.010)	(0.009)
$\Delta\ln(Wage_{it}) \times$ Year=21		0.104**
		(0.046)
$s_i \cdot \Delta\ln(p_{it,imp})$	0.225***	0.177***
	(0.027)	(0.024)
$s_i \cdot \Delta\ln(p_{it,imp}) \times$ Year=21		0.469***
		(0.117)
$\Delta\ln(A_{it})$	-0.095***	-0.079***
	(0.010)	(0.009)
$\Delta\ln(A_{it}) \times$ Year=21		-0.104**
		(0.046)
Time Fixed Effects	Yes	Yes
Industry Fixed Effects	Yes	Yes
Worker Composition	Yes	Yes
Observations	10,038	10,038

B.2 Domestic Competitors

One issue with our findings in the main text is that we do not control for domestic competitors. Some of the correlation of prices with input costs and wages could be due to a response to domestic competitors' price changes. While our industry-level data do not permit us to take into account within-industry competition, we construct a measure of domestic competition using the price index at the more aggregated 4-digit NAICS industry level. Specifically, we compute for each 6-digit industry a 4-quarter producer price change of the associated 4-digit industry in each quarter by taking a weighted average across the 4-quarter PPI changes of all associated 6-digit industries, using total shipments in 2021 as weight. We include the resulting variable $\Delta \ln(p_{it}^{PPI4})$ in the regression, interacted with industry i's domestic share, $1 - s_i$. To be consistent, we construct the foreign competitors' price change analogously.

The results in column 1 of Table A.2 still indicate a positive correlation of prices in the goods sector with input prices, wages, and foreign competitors' prices. In addition to that, we also find a positive correlation with our proxy for domestic competitors. In column 2, we further add interactions with 2021 and find that pass-through of input prices and wages increased in that year, as before. While we do find a strengthening correlation of producer prices with foreign competitors' prices, we do not find a similar strengthening of the correlation with domestic competitors' prices. Column 3 presents our non-linear specification results. As before, we find a positive and significant interaction between wage changes and input price changes in 2021.

B.3 Regression With Shift in Demand

A concern with our analysis is that while we focus on changes in input costs, demand factors could also be responsible for our findings. To examine whether an increase in demand could be behind our results, we re-run our baseline analysis in the goods sector with time-by-3-digit NAICS industry fixed effects. These fixed effects sweep out any variation that occurs at the broad 3-digit industry level. If demand shocks affect all industries that are part of a broader 3-digit aggregate equally, then the remaining variation is due to supply factors. Since the productivity measure is at most at the 3-digit level, this regression does not separately identify a productivity effect.

Column 1 of Table A.3 shows pass-through coefficients very similar to those in our baseline regression. Thus, most of the variation we pick up is due to variation within 3-digit industries. Column 2 shows that as before we find a significant pick-up in the correlation between domestic prices, wages, and input prices in 2021. The final column shows the results from the non-linear specification. As in the baseline, we find a significant and positive interaction

Table A.2: Pass Through for Domestic Competitors, 2013:Q1 - 2021:Q3

	(1) $\Delta\ln(p_{it})$	(2) $\Delta\ln(p_{it})$	(3) $\Delta\ln(p_{it})$
$\Delta\ln(p_{it,input})$	0.123***	0.094***	0.126***
	(0.019)	(0.019)	(0.019)
$\Delta\ln(p_{it,input}) \times$ Year=21		0.084***	-0.049
		(0.018)	(0.066)
$\Delta\ln(Wage_{it})$	0.033**	0.013	0.005
	(0.016)	(0.012)	(0.010)
$\Delta\ln(Wage_{it}) \times$ Year=21		0.161***	0.082***
		(0.016)	(0.028)
$\Delta\ln(Wage_{it}) \times \Delta\ln(p_{it,input})$			-0.602**
			(0.247)
$\Delta\ln(Wage_{it}) \times \Delta\ln(p_{it,input}) \times$ Year=21			0.740**
			(0.301)
$s_i \times \Delta\ln(p^{PPI4}_{it,imp})$	0.239***	0.173***	0.164***
	(0.051)	(0.019)	(0.017)
$s_i \times \Delta\ln(p^{PPI4}_{it,imp}) \times$ Year=21		0.551***	0.588***
		(0.133)	(0.132)
$(1 - s_i) \times \Delta\ln(p^{PPI4}_{it,input})$	0.555***	0.502***	0.461***
	(0.025)	(0.039)	(0.043)
$(1 - s_i) \times \Delta\ln(p^{PPI4}_{it,input}) \times$ Year=21		0.057	0.008
		(0.045)	(0.040)
$\Delta\ln(A_{it})$	-0.088***	-0.090***	-0.084***
	(0.013)	(0.015)	(0.016)
$\Delta\ln(A_{it}) \times$ Year=21		0.012	-0.040
		(0.035)	(0.047)
Time Fixed Effects	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes
Worker Composition	Yes	Yes	Yes
Nonlinear Effects	No	No	Yes
R2	0.228	0.238	0.242
Observations	10,322	10,322	10,322

effect in 2021.

Table A.3: Pass Through with Time-by-Industry Fixed Effects, 2013:Q1 - 2021:Q3

	(1) $\Delta\ln(p_{it})$	(2) $\Delta\ln(p_{it})$	(3) $\Delta\ln(p_{it})$
$\Delta\ln(p_{it,input})$	0.304***	0.231***	0.271***
	(0.055)	(0.042)	(0.047)
$\Delta\ln(p_{it,input}) \times$ Year=21		0.167***	-0.050
		(0.060)	(0.099)
$\Delta\ln(Wage_{it})$	0.027	0.009	0.003
	(0.019)	(0.016)	(0.011)
$\Delta\ln(Wage_{it}) \times$ Year=21		0.112***	-0.038
		(0.018)	(0.056)
$s_i \cdot \Delta\ln(p_{it,imp})$	0.202***	0.161***	0.161***
	(0.041)	(0.028)	(0.028)
$s_i \cdot \Delta\ln(p_{it,imp}) \times$ Year=21		0.401***	0.416***
		(0.142)	(0.151)
$\Delta\ln(Wage_{it}) \times \ln(p_{it,input})$			-0.616*
			(0.345)
$\Delta\ln(Wage_{it}) \times \Delta\ln(p_{it,input}) \times$ Year=21			1.886***
			(0.415)
Time by 3-digit Industry Fixed Effects	Yes	Yes	Yes
Worker Composition	Yes	Yes	Yes
R2	0.062	0.075	0.078
Observations	10,038	10,038	10,038