Global Value Chains and the Dynamics of UK Inflation *

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October 2023

Abstract

This paper explores the link between the UK's participation in global value chains (GVCs) and inflation dynamics. Using a two-country model with input-output linkages, we demonstrate analytically that an increased reliance on imported intermediate goods, serving as a GVC proxy, results in a flatter Phillips curve. Empirically, we find evidence indicating that UK industries with higher proportions of intermediate imports from Emerging Market Economies (EMEs) exhibit a flatter Phillips curve. This observation stems not only from the impact of the GVC integration on the slope but also from the influence of cyclical forces that shape firms' marginal costs via international relative price fluctuations. Specifically, we highlight how the limited business cycle correlation between the UK economy and EMEs reduces the pass-through of domestic shocks to prices.

Keywords: Global value chains, inflation dynamics, Phillips curve.
JEL codes: E30, E31, E32, F10, F14.

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*Any views expressed are solely those of the authors and so cannot be taken to represent those of the Bank of England and the IMF. For helpful comments and suggestions, we thank Laura Alfaro, Ravi Balakrishnan, Laurence Ball, Ambrogio Cesa-Bianchi, Diego Comin, Giancarlo Corsetti, Sophie Guilloux-Nefussi, Simon Gilchrist, Ida Hjortsoe, Simon Lloyd, Riccardo Masolo, Stephen Millard, Ricardo Reis, Rana Sajedi, Ayşegül Şahin, Boromeus Wanengkirtyo, Jonathan Wright and Robert Zymek. We are also grateful to participants at numerous seminars and conferences including at the Bank of England, Johns Hopkins University, LSE and NY FED. We also thank Veronica Veggente for her research assistance.

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1 Introduction

Over the last few decades, the rise in global value chains (GVCs) has led to increasingly interlinked production processes across countries and sectors, making firms' pricing decisions much more dependent on foreign factors. The implications of globalisation of production for inflation dynamics have become even more central after the supply-chain disruptions following the COVID-19 crisis.

In this paper, we investigate whether the integration of the UK economy into GVCs has affected the link between domestic output and inflation. Most of the existing literature exploring the impact of globalisation on shaping domestic inflation dynamics primarily concentrates on the US. Here, our focus shifts to the UK, due to its high degree of openness and substantial integration into GVCs. This implies a more pertinent role for GVCs in the international transmission of shocks.

First, we show that the slope of the UK Phillips curve flattened substantially in the late 1990s before becoming insignificant during the 2000s. To do so, we use aggregate and sectoral data from the UK. Then we document that the share of imported intermediate goods in the UK's production dramatically increased over the period 2000-2014. We observe that the UK's manufacturing sector became more integrated into GVCs than its services sector. Importantly, we find that although the level of imported intermediate input share is much larger from the EU and advanced economies (AEs) than that from emerging market economies (EMEs), the primary increase in the share of imported intermediate goods within the manufacturing sector during the 2000s is attributable to EMEs, particularly to the role of China.

Second, we demonstrate analytically that a rise in the share of imported intermediate goods flattens the Phillips curve. We build a static two-country New Keynesian model that incorporates trade in both intermediate and final goods. This model allows us to delve into the theoretical connection between GVC integration and the slope of the Phillips curve. GVC integration results in firms employing a higher amount of imported intermediate inputs in their production, thereby reducing the sensitivity of their marginal cost to domestic wage pressures. Consequently, domestic inflation becomes increasingly linked to the foreign output gap in the presence of integration to GVCs.

Third, we discover that UK industries with higher proportions of intermediate imports from EMEs exhibit flatter sectoral Phillips curves. We employ industry-level data to examine the impact of an increased proportion of imported intermediate inputs on the response of the sectoral Producer Price Index (PPI) to the sectoral output gap over the 2000-2014 period. Our findings indicate that greater integration into

GVCs is not consistently associated with flatter Phillips curves. Rather, it is the *interaction* between the sectoral and source-country dimensions that drives this flattening effect.

While integration with China constitutes an influential factor, this phenomenon is not exclusive to China alone. Integration with other EMEs also significantly weakens the response of UK inflation to the output gap. Importantly, this result withstands various specifications, including the use of an instrumental variable approach inspired by Autor et al. (2013).

Fourth, we investigate why the previous result holds only for EMEs but not advanced economies. We find that GVCs affect the relationship between inflation and real economic activity through two channels: i) the slope channel; for given prices abroad, the higher the imported input share, the lower the response of inflation to an increase in domestic demand ii) the relative price channel; for a given slope, the lower the relative price of imported inputs, the lower the response of inflation to an increase in domestic demand. The latter channel is especially important for small open economies like the UK as they cannot alter the world prices.

To do this, we extend our static two-country New Keynesian model to a multi-sector DSGE model to fully account for the determinants of the GVCs measure we use in our empirical analysis. According to our model, the measure we use is not only a function of imported intermediate inputs *share* but also a function of international relative prices. Terms of trade fluctuations affect the empirical measure of GVCs through their impact on marginal cost. When firms use imported intermediates in their production, marginal cost does not only move with the fluctuations in wages (or cost of value added) but also moves with domestic and imported intermediate input prices. The relative price of imported to domestic intermediate inputs, i.e. the terms of trade, allows firms to switch between domestic and foreign inputs in response to shocks reducing the pass-through from wages to prices.

It is well-known in international macroeconomics literature that business cycles are highly correlated across developed economies. Put differently, when demand increases in the UK, it also increases in other AEs. This limits the degree of fluctuations in the terms of trade, a fact that is clearly visible in our sample period over which the business cycle correlation of the UK economy is lower with EMEs than AEs. Specifically, we show that, in our sample period, the correlation of the UK's output with AEs is on average 74% while with EMEs is 40%.

Finally, we test the importance of these medium-term forces for our benchmark results and find that a rising imported intermediate goods share from countries with low business cycle correlation with the UK leads to a fall in response of inflation to real economic activity. We do not find a significant role for imported intermediates from countries with high business cycle correlations with the UK. We argue that this relative price channel may be an important driver of our results.

Related Literature The positive relationship between inflation and the output gap lies at the centre of New Keynesian DSGE models. Changes in this relationship have important implications for the transmission of monetary policy. Therefore, academics and policymakers have extensively explored the importance of globalisation for the degree to which inflation responds to fluctuations in real economic activity (e.g. Auer and Fischer, 2010; Borio and Filardo, 2007; Forbes, 2019a,b; Forbes et al., 2020; Heise et al., 2022; Obstfeld, 2019). Our empirical strategy is similar to Gilchrist and Zakrajsek (2019). By using industry-level data, they show that increased integration of the US economy to trade is important in explaining the fall in the response of inflation to the domestic output gap. We also rely on industry-level data but instead of looking at trade integration, which includes both trade in final and intermediate goods, we investigate the role of imported intermediate goods only.

In this respect, our paper is more related to studies that focus on the trade in intermediate inputs aspect of globalisation such as Auer et al. (2017) and Auer et al. (2019). We differ from this empirical literature in two dimensions: First, the literature tends to be focused primarily on the US and second does not consider the importance of integration of EMEs into the GVCs. In this paper, we show that investigating this channel both empirically and theoretically is crucial to shed light on the inflation dynamics of a *small open economy* like the UK.

On the modelling side, our contribution is to study the role of input-output linkages in understanding inflation dynamics in an *open economy* setting. In a closed economy setting, by building a multi-sector New Keynesian model with input-output linkages, Rubbo (2020) shows that the use of intermediate inputs lowers the slope of the Phillips curve. By using a similar framework in an open economy setting, we instead show how trade in intermediate inputs leads to a fall in the slope of the Phillips curve.

There is also a relatively large literature that studies the transmission of shocks within frameworks that include production networks (Galesi and Rachedi (2019), Höynck (2020), Pasten et al. (2020) etc.). We contribute to this literature by emphasising the importance of terms of trade movements for the pass-through from wages to inflation in response to shocks. Our paper is closest to Comin and Johnson (2020). They build an open economy New Keynesian framework with trade in both intermediate inputs and final goods and analyse the impact of an input trade shock on US inflation. They focus on the impact of a permanent shock on trade openness and show that this shock does not lead to a fall in inflation. We do not focus on a shock that increases the imported inputs share in production but instead, we analyse whether intermediate input trade lowers the response of domestic inflation to domestic slack. We show that this is indeed the case both through the slope and also through international relative price movements.

Outline The remainder of the paper is structured as follows. Section 2 presents some motivational evidence on the reduced form correlation between the UK's inflation and the output gap at the aggregate level and on the increased importance of trade in intermediate inputs for the UK. Section 3 describes the theoretical framework for the relationship between the input trade and the slope of the Phillips curve. Section 4 presents the main empirical results with robustness checks in section 5. In section 6 we extend our model to a dynamic setting and discuss the importance of medium-term forces. Finally, section 7 concludes.

2 Global Value Chains and the Phillips Curve

In this section, we start by providing reduced-form evidence on the flattening of the UK's Phillips Curve. We then present some stylized facts related to imports of intermediate goods in the UK over time.

2.1 Aggregate Phillips Curve

We begin by presenting the patterns of the UK's inflation and output gap relationship since the beginning of the 1990s. To present the trends in the slope of the UK Phillips curve, we estimate the following specification using (15-year) rolling windows regressions:

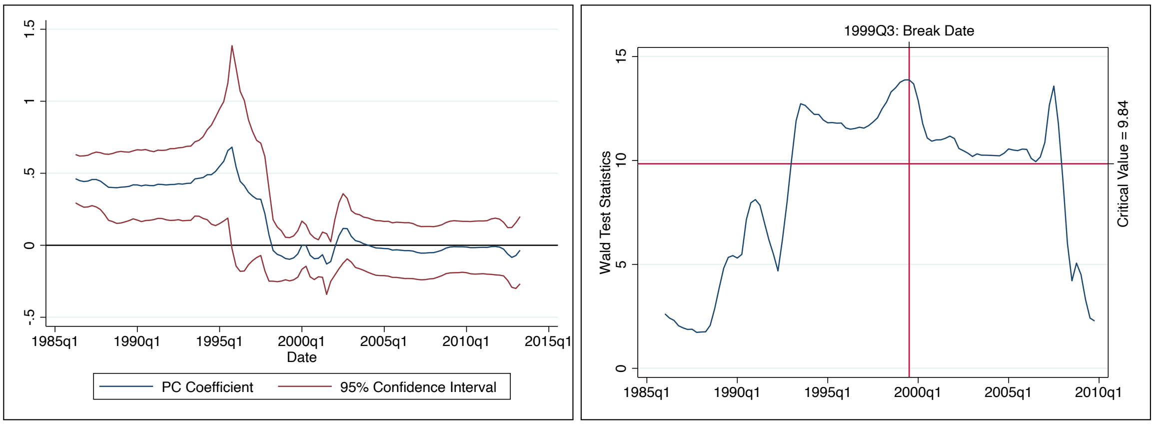
$$\pi_t = \beta_1(y_t - y_t^*) + \beta_2 \left(\frac{1}{4} \sum_{j=1}^{4} \pi_{t-j} \right) + \beta_3 \pi_t^M + \beta_4 \pi_t^{Oil} + \varepsilon_t, \tag{1}$$

where π_t is the year-over-year percentage change in CPI, π_t^M is the import price deflator, π_t^{oil} denotes crude oil price index, and $(y_t - y_t^*)$ is the output gap measured by using the HP-filtered real GDP.[1] Details about the data sources can be found in Appendix A. We assume adaptive expectations such that the expected inflation rate

[1]We use CPI inflation throughout this section. Results are robust to using Retail Price Index inflation.

Figure 1: The Flattening of the UK Phillips Curve

(a) Rolling sample regression results **(b)** Wald structural break test



Note: Panel (a) presents estimation results from Equation 1 and Newey-West standard errors are computed with a lag length of 18.

equals average inflation in the previous four quarters ($\pi_t^e = \frac{1}{4}\sum_{j=1}^{4}\pi_{t-j}$) following Ball and Mazumder (2011).[2] Our sample period starts at 1980Q1 to leave out the high inflationary period of the 1970s.

Figure 1a displays the change in the slope of the Phillips curve. The Phillips curve coefficient has been positive, significant, and stable since the 1980s until it began flattening during the mid-1990s and became insignificant afterwards.[3]

Figure 1b investigates this evidence more formally, searching for structural breaks in Phillips curve coefficient (β_1) using a Sup-Wald test from Andrews (1993). Specifically, we calculate a Wald test statistic for every date between 1985Q1 and 2010Q1 and test whether the null hypothesis that there is no break in the Phillips curve relationship can be rejected. The red line presents the critical value for the test. The results suggest 1999Q3 as the specific break date, confirming the rolling window regressions from Figure 1a.

Lastly, we estimate Equation 1 for the full sample, before and after the break date 1999Q3 to highlight the dramatic change in the inflation and output gap relationship. Column (1) points to an insignificant Phillips curve relationship from the full sample. However, pre-break sample (column (2)) suggests a positive and significant relationship between inflation and the output gap. On the other hand, column (3) implies that this relationship has been broken between 1999Q3 and 2017Q1. We next provide sectoral evidence on the increased importance of GVCs for the UK economy and

[2]The results are robust to using quarterly lagged inflation variables separately in the regressions.

[3]The weakened relationship between the inflation and the output gap can also be seen in Appendix B, Figure 7 where we plot the aggregate UK inflation against the output gap.

Table 1: UK Phillips curve over different time periods

π_t	(1) (1980Q1-2017Q1)	(2) (1980Q1-1999Q2)	(3) (1999Q3-2017Q1)
$(y_t - y_t^*)$	0.124	0.374***	-0.222
	(0.183)	(0.0784)	(0.168)
π_t^M	0.0924**	0.0513	0.161***
	(0.0466)	(0.0459)	(0.0438)
π_t^{oil}	0.0131*	0.0170*	0.000157
	(0.00696)	(0.00999)	(0.00630)
$\frac{1}{4}\sum_{j=1}^{4}\pi_{t-j}$	0.885***	0.905***	1.722***
	(0.0548)	(0.0447)	(0.232)
Observations	149	80	69
R^2	0.9203	0.9581	0.8547

Notes: The results are from the estimation of Equation (1). The cutoff date of 1999Q3 follows the structural break test from Figure 1b. Newey-West standard errors are in parentheses with a lag of 18. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

propose an explanation for the weakening in the slope of the UK Phillips curve and changing inflation dynamics.

2.2 GVCs

Having shown the weakened relationship between the UK's inflation and real economic activity, we now present evidence of the increasing dependence of UK production on imported intermediate inputs. We use the World Input-Output Database (WIOD) to calculate the imported intermediate good share in total inputs used for production across each sector as our GVC integration measurement. Our main GVC integration measurement, imported intermediate good share, is

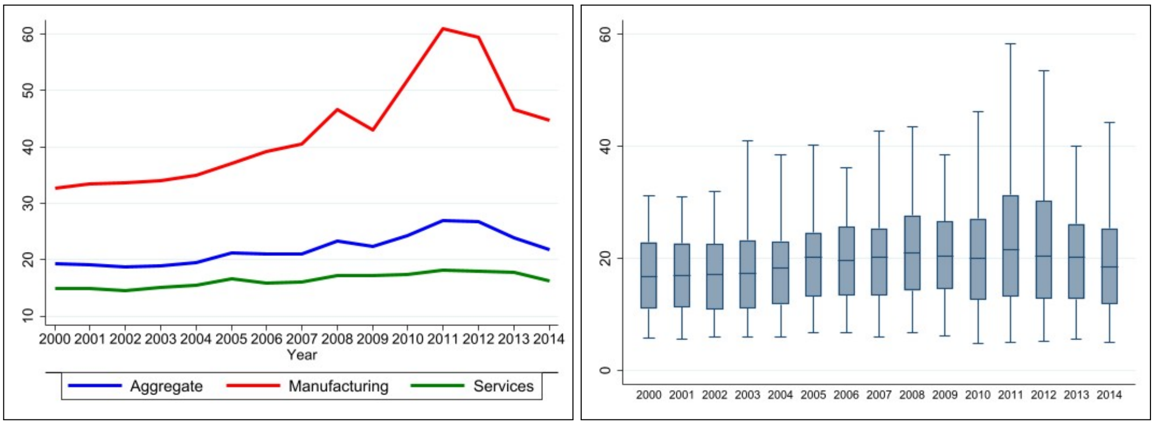
$$IIS_{j,t} = \frac{\text{Imported Intermediate Goods}_{j,t}}{\text{Total Intermediate Goods}_{j,t}}, \tag{2}$$

where j denotes sector, and we calculate $IIS_{j,t}$ for 40 sectors between 2000 and 2014.

We use WIOD to provide evidence of the increasing dependence of the UK economy on imported goods. Specifically, we calculate the share of imported intermediate goods in total intermediate goods used in production, across broad categories. The blue line in figure 2a shows the slight increase in imported intermediate good dependence at the aggregate level. However, aggregate series mask the heterogeneity in trends between manufacturing and service sectors. The manufacturing sector imported intermediate goods share (red line) increased from 31% to 61% between 2000

Figure 2: UK's integration in the global economy

(a) Imported intermediate good share **(b)** Imported intermediate good share (Sectoral)



Note: Panel (a) presents Imported Intermediate Good Share: $\frac{\text{Imported Intermediate Goods}}{\text{Total Intermediate Goods}}$ using WIOD data. Panel (b) displays the sectoral imported intermediate good share distribution across 56 sectors from WIOD.

and 2012 whereas this share has been stable in the service sector (blue line) during this period.[4]

Figure 2b shows the distribution of $IIS_{j,t}$ over time across 56 sectors available in WIOD using box plots. We observe that the median $IIS_{j,t}$ (red line) slightly increased during this period. Importantly, the rise in integration has been experienced at different rates across sectors, providing heterogeneity in both cross-section and time series. We will build out an empirical strategy in section 4 to exploit this heterogeneity and identify the role of GVCs on the UK inflation dynamics. In the next section, we will build a theoretical framework to understand the relationship between GVCs and the slope of the Phillips curve.

3 A Model of Global Value Chains

How does GVC integration affect the Phillips curve relationship? In this section, we build a two-country, New-Keynesian model with trade in intermediate and final goods. We build on the work of Rubbo (2020) to derive a theoretical relationship between GVC integration and the Phillips curve.

[4]The integration to the GVCs has also been realized at a relatively higher rate in the UK than in other advanced countries. This can be seen in Appendix B Figure 5, which shows the comparison in "the change" in IIS from 2000 across four selected advanced countries.

3.1 Outline of Model

Households The global economy consists of a home and foreign economy, each producing a differentiated good in the spirit of Armington (1969). Throughout the paper, we use the notation $'' * ''$ to capture variables in the foreign economy. We abstract from multiple sectors for simplicity.[5] Households in the home economy consume and supply labour and have preferences

$$U = \frac{C^{1-\sigma}}{1-\sigma} - \Xi \frac{L^{1+\varphi}}{1+\varphi},$$

where σ and φ denote the inverse of the intertemporal elasticity of substitution and Frisch elasticity of labor supply, respectively. The consumption bundle in turn consists of home and foreign goods

$$C = C_H^{\alpha} C_F^{1-\alpha},$$

where α represents the expenditure share of home goods. As in De Paoli (2009), the share of imported goods in each country is a function of relative country size, $1-n$, and the degree of openness in final demand, v_C: $1-\alpha = (1-n)\, v_C$. When $\alpha > 0.5$, there is home bias in preferences. A similar expression holds for households in the foreign economy.

Production Firms in each economy are identical and use labor (L) and intermediate inputs (M) to produce a unit of output. The production function has the following constant-returns-to-scale functional form:

$$Y_H(i) = AL(i)^{\delta} M(i)^{1-\delta},$$

where Y_H denotes firm i's gross-output of home goods, A is the aggregate productivity and δ denotes the share of labor in production. Intermediate goods used by the firms are a CES aggregate of home and foreign-produced intermediate inputs:

$$M(i) = \left[\mu^{\frac{1}{\phi}} \left(M_H(i)\right)^{\frac{\phi-1}{\phi}} + (1-\mu)^{\frac{1}{\phi}} \left(M_F(i)\right)^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}}.$$

The parameter $(1-\mu)$ captures the share of intermediate goods that are imported from abroad. Similar to the consumption preference structure, we assume that the

[5]Extending to a multi-sector setup would allow for an additional dimension of heterogeneity in the price-stickiness across sectors, and the centrality of sectors in the production network. We abstract from a multi-sector setup in this static model for simplicity.

share of imported intermediate goods is a function of relative country size, $(1-n)$, and the degree of openness in intermediate goods in a sector, v_M: $1-\mu=(1-n)\,v_M$.

Pricing To introduce a Phillips Curve into the model, we allow for nominal rigidities in the form of sticky-information as in Mankiw and Reis (2002). The timing within the period is as follows:

1. All firms pre-set their price as a markup over the expected marginal cost
2. A fraction 1-θ of firms are able to observe aggregate shocks in the economy
3. Firms who observe aggregate shocks are able to change their price

We assume that all firms price goods according to producer currency pricing, therefore there is a perfect exchange rate pass-through. Thus, home and foreign firms pre-set their price to

$$P_H^{\#}(i)=\frac{\epsilon}{\epsilon-1}\mathbb{E}[MC], \tag{3}$$

$$P_F^{*\#}(i)=\frac{\epsilon}{\epsilon-1}\mathbb{E}[MC^*], \tag{4}$$

where the expectation is taken over aggregate states. A fraction 1-θ of home (1-θ^* of foreign) firms are able to observe aggregate shocks and hence update their price. These firms change their prices to

$$\widetilde{P}_H(i)=\frac{\epsilon}{\epsilon-1}MC, \tag{5}$$

$$\widetilde{P}_F^*(i)=\frac{\epsilon}{\epsilon-1}MC^*, \tag{6}$$

The aggregate price level at the end of the period is given by

$$P_H^{1-\epsilon}=\theta P_H^{\#1-\epsilon}+(1-\theta)\tilde{P}_H^{1-\epsilon},$$

and inflation is given by

$$\Pi_H^{1-\epsilon}=\theta+(1-\theta)\left(\frac{MC}{\mathbb{E}[MC]}\right)^{1-\epsilon},$$

where $\Pi_H\equiv\frac{P_H}{P_H^{\#}}$. Thus inflation is defined as the change in prices relative to the pre-set price before any shocks hit the economy. Inflation occurs when the actual marginal cost rises above the expected marginal cost. We can linearise this equation as

$$\log\Pi_H\equiv d\log P_H=(1-\theta)d\log MC,$$

where

$$d\log P_H \equiv \log P_H - \log P_H^{\#},$$
$$d\log MC \equiv \log MC - \log \mathbb{E}[MC].$$

A symmetric expression holds for the foreign economy.

Trade Trade of both final goods and intermediate goods arises in the economy. We assume that there is balanced trade in both final and intermediate goods in equilibrium.

$$nP_F(C_F + M_F) = (1-n)P_H(C_H^* + M_H^*). \tag{7}$$

3.2 The Global Phillips Curve

We define the following notation:

$$\log \mathbf{p} = \begin{pmatrix} \log P_H \\ \log P_F^* \end{pmatrix}, \quad \log \mathbf{W} = \begin{pmatrix} \log W \\ \log W^* \end{pmatrix}, \quad \log \mathbf{A} = \begin{pmatrix} \log A \\ \log A^* \end{pmatrix}, \quad \boldsymbol{\delta} = \begin{pmatrix} \delta \\ \delta^* \end{pmatrix}, \quad \mathbf{1} = \begin{pmatrix} 1 \\ 1 \end{pmatrix},$$

$$\Phi = \begin{pmatrix} \alpha & 1-\alpha \\ 1-\alpha^* & \alpha^* \end{pmatrix}, \qquad \Omega = \begin{pmatrix} 1-\delta & 0 \\ 0 & 1-\delta^* \end{pmatrix} \begin{pmatrix} \mu & 1-\mu \\ 1-\mu^* & \mu^* \end{pmatrix}.$$

Ω represents the global input-output matrix. Let $\log \boldsymbol{P} = \Phi \log \boldsymbol{p}$ denote the vector of (log) CPI inflation

Proposition 1. The Global Phillips Curve can be written as

$$d\log \mathbf{P} = \mathcal{K}\tilde{y} + \mathcal{G}d\log \mathbf{A} + \mathcal{H}d\log \mathcal{E}, \tag{8}$$

where $\mathcal{K} = \Phi\Theta(I-\Omega\Theta)^{-1}\delta[I - ((1+\sigma\Phi - \sigma I)\Theta(I-\Omega\Theta)^{-1}\delta]^{-1}(\sigma+\varphi)$ and $\mathcal{E}$ is the nominal exchange rate (units of foreign currency in home currency). The proof and expressions for the $\mathcal{G}, \mathcal{H}$ matrices are shown in Appendix E. The main diagonal of $\mathcal{K}$ represents the *slope* of the Phillips Curve - the dependence of CPI inflation on the domestic output gap. The off-diagonal elements of $\mathcal{K}$ capture the dependence of domestic inflation on the foreign output gap. This leads us to the following corollary.

Corollary 1. The higher the imported intermediate good share, the flatter the Phillips curve. Mathematically,

$$\frac{d\mathcal{K}_{ii}}{d(1-\mu_i)} < 0.$$

Intuitively, as firms depend more on intermediate inputs imported from abroad, their marginal costs are less exposed to the domestic output and more exposed to foreign output. As a result, inflation depends less on the domestic output gap and more on the foreign output gap. Given that the share of imported goods (both final demand and intermediate) is proportional to the country size as in De Paoli (2009), the relative country size will matter for the slope through α and μ. Smaller countries like the UK are more open, so all else equal should have a flatter Phillips Curve. In addition, unsurprisingly, the Phillips Curve become steeper as labour share increases, consistently with the standard three-equation closed-economy New Keynesian model.

Besides the slope effect, the price-stickiness of domestic and foreign goods is also amplified along the production network. The price stickiness of foreign goods implies that the cost of imported intermediate goods, and hence the marginal costs for home firms do not rise by as much as in the flexible-price case. This then implies that domestic prices do not rise by as much. Note that this channel also interacts with the degree of exchange rate pass-through. Under producer currency pricing, the price of goods is sticky in the currency of the producer. Therefore, the changes in import prices transmit through the nominal exchange rate which is captured in the $\mathcal{H}$ matrix.

The following section will introduce a reduced-form model exploiting this heterogeneity in a panel to structure to identify the role of integration to GVCs on the flattening of the UK Phillips curve.

4 Sectoral Phillips Curve and GVCs

Can the use of imported inputs in production, at least partly, explain the flattening of the UK Phillips curve documented in Section 2? Guided by our model, we argue that the increased use of imported intermediates in production may make the prices in the UK economy less dependent on domestic factors. Therefore, the relationship between inflation and domestic economic activity may weaken. This section analyzes the role of rising imported intermediate good share on the UK Phillips curve using a sectoral Phillips curve.[6]

[6] We also look at whether aggregate trade openness can be related to the weakened relationship between the UK's inflation and the output gap. We find supporting evidence that rising trade openness in the UK led to a flattening in the Phillips curve. However, given that the estimations at the aggregate level are subject to identification issues and that our focus is trade in intermediate inputs, we do not report the results in the main text. See, Appendix C for details.

We combine quarterly ONS inflation and output data with the annual WIOD for 40 UK industries between 2000Q1 and 2014Q4.[7] Interacting the imported intermediate good dependence series with the sectoral output gap, we examine the role of GVCs and in particular GVC integration to the EMEs on the inflation and output gap relationship in reduced-form.[8]

To investigate the relation between GVCs and inflation, we estimate the following specification for the period 2000Q1-2014Q4

$$\pi_{j,t} = \beta_1 \left(y_{j,t} - y^*_{j,t} \right) + \beta_2 IIS_{j,t} + \beta_3 \left(y_{j,t} - y^*_{j,t} \right) \times IIS_{j,t} + \beta_4 \left(\frac{1}{4} \sum_{k=1}^{4} \pi_{j,t-k} \right) + \delta_j + \delta_t + \varepsilon_{j,t}, \tag{9}$$

where $IIS_{j,t}$ is defined above as the ratio of imported intermediate goods in total intermediate goods in sector j at time t. To provide clarity in interpretation, $IIS_{j,t}$ is standardized (around the mean). Sectoral inflation series $\pi_{j,t}$ are calculated as the four-quarter percentage change in PPI and SPPI, and sectoral output gap $\left(y_{j,t} - y^*_{j,t} \right)$ is the deviation of production index series (IoP and IoS) from their HP filtered trends.[9] The rich panel data allow us to control for time-invariant sector-specific factors using sector fixed-effects (δ_j) as well as time-varying aggregate factors affecting inflation such as monetary policy (McLeay and Tenreyro (2020)) and inflation expectations (Ball and Mazumder (2019)) using time fixed-effect (δ_t).[10]

Section 2 showed that the slope of the UK Phillips curve could not be precisely estimated using aggregate data after 2000. We now test whether we can provide a better precision in the Phillips curve coefficient (β_1) using sectoral data during this period. Then, importantly, we assess the role of the integration into the GVCs on the flattening of the UK Phillips curve by estimating the coefficient of the interaction term (β_3). A negative interaction term would imply that more GVC integration is associated with lower responsiveness of inflation to the output gap.

Estimating Equation 9, Table 2 presents the results. Column (1) shows the positive and significant relationship between sectoral inflation and the output gap. Recalling the insignificant Phillips curve coefficient from the aggregate data, we present that the UK Phillips curve can be precisely estimated using sectoral data. This result is in line

[7] We can merge trade, price, and output data for 40 out of 56 WIOD sectors with a balanced panel, and they comprise 70% of total output in the UK.

[8] Inflation and output data are always winsorized at 1st and 99th percentiles. Results are qualitatively unchanged if we do not winzorize the data.

[9] Both sectoral inflation and output series are at a quarterly frequency and $IIS_{j,t}$ is available at the annual frequency.

[10] We use *year* fixed-effects in our benchmark analysis, however, our results are robust to using *quarterly* fixed effects. Results from these estimations are available upon request from the authors.

Table 2: GVCs and the UK Phillips Curve

2000Q1-2014Q4 Dep Var: $\pi_{j,t}$	(1) Only Output Gap	(2) Role of GVCs
$(y_{j,t} - y^{*}_{j,t})$	0.0430***	0.0419***
	(0.0138)	(0.0118)
$IIS_{j,t}$		0.616
		(0.533)
$(y_{j,t} - y^{*}_{j,t}) \times IIS_{j,t}$		-0.0164
		(0.0197)
Average of Lags	0.376***	0.373***
	(0.0429)	(0.0449)
Industry FE	Y	Y
Time FE	Y	Y
No of Obs.	2158	2158
R^2	0.251	0.255

Note: Results are from Equation 9. Column (1) uses the equation without $IIS_{j,t}$ term. Column (2) estimates the full equation. Driscoll-Kraay standard errors are in parenthesis with a lag of 8.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

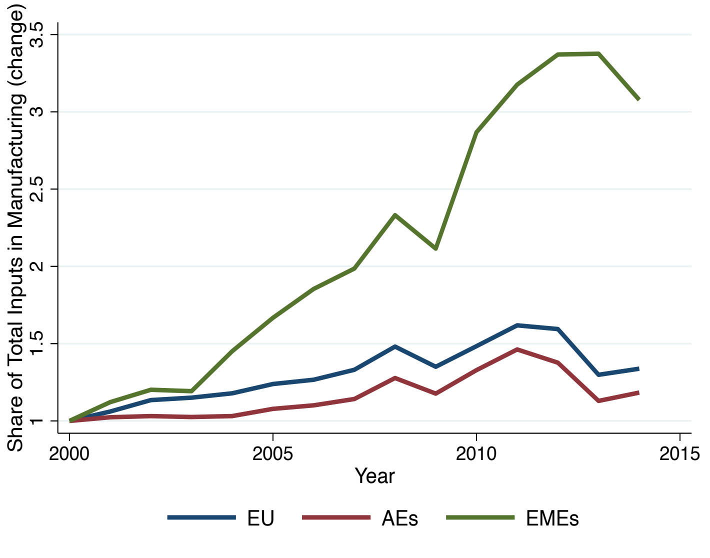
with the McLeay and Tenreyro (2020) critique that a successful monetary policy might have caused a flattening in the Phillips curve by reacting to inflation at the right time and muting its response following demand-side shocks. However, exploiting the rich panel structure in inflation and output gap and after controlling for aggregate level time-varying trends with time fixed-effects, we find a positive and significant Phillips curve coefficient in the UK after 2000.

Moving to our main argument that increasing integration might be an important cause of the flattening of the UK Phillips curve, we present the results from the interaction of the sectoral output gap with the imported intermediate good share in column (2). The coefficient of the interaction term (the third row) is negative, pointing to a role for GVCs in explaining the heterogeneity in inflation and output gap relationship across sectors. However, the coefficient is insignificant, implying an insufficient heterogeneity in $IIS_{j,t}$ to precisely estimate the role of GVCs on the flattening of the UK Phillips curve. Next, we will examine the sources of heterogeneity in integration to the GVCs in terms of the sources of imports.

4.1 Role of the Source of Integration

Digging deeper into the data, we reveal two striking facts. First, for the manufacturing sector, the increase in the UK's imported intermediate goods share is almost entirely attributable to Emerging Market Economies (EMEs), with the share of the European Union (EU) and Advanced Economies (AEs) remaining relatively stable between 2000

Figure 3: The share of regions in total inputs: Change from the initial level



Note: The series presents the aggregate imported intermediate good share from different regions IIS^{EU}, IIS^{AEs}, IIS^{EMEs}. These are weighted averages of sectoral imported intermediate good shares ($IIS^{EU}_{j,t}$, $IIS^{AEs}_{j,t}$, $IIS^{EMEs}_{j,t}$). The shares are normalized to 1 in 2000. Country classifications follow IMF and details are provided in Appendix A.

and 2014 (Figure 3). For example, the integration of the UK manufacturing sector to EMEs was more than three times larger in 2013 than its level in 2000.

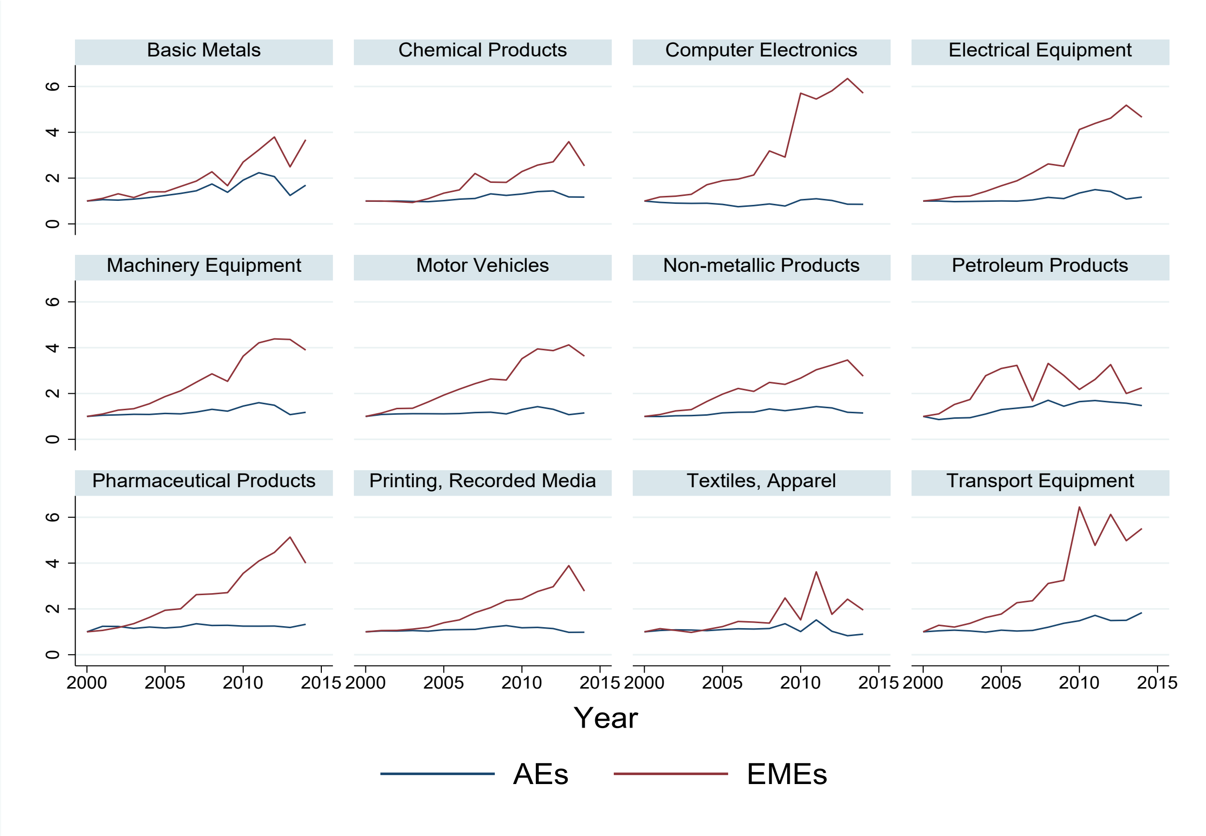
After showing that the UK manufacturing sector has integrated into the EMEs since 2000, we here present considerable heterogeneity in dependence on EME inputs within the manufacturing sector. Figure 4 compares the change in the share of AEs and EMEs in intermediate goods used by each sector in the UK. The figure displays the widespread rise in integration to the EMEs compared to the stable levels in dependence on the AE imports between 2000 and 2014. The integration is more striking in sectors such as "Computer Electronics," "Electrical equipment" and "Transport equipment," reaching up to six times higher share in intermediate goods used in these sectors. By decomposing the $IIS_{j,t}$ variable into regional sources of imports, we observe the heterogeneity comes from the EMEs rather than AEs or EU countries.[11]

To formally differentiate the roles of integration of the UK sectors to different regions, we estimate Equation 9 distinguishing between different source-region in variable $IIS_{j,t}$ such that

$$IIS^{AEs}_{j,t} = \frac{\text{Imported Intermediate Goods}^{AEs}_{j,t}}{\text{Total Intermediate Goods}_{j,t}}, \quad IIS^{EMEs}_{j,t} = \frac{\text{Imported Intermediate Goods}^{EMEs}_{j,t}}{\text{Total Intermediate Goods}_{j,t}},$$

[11]Note that the level of imported intermediate goods is much higher from AEs than EMEs. However, the change in our sample, which is our focus, can be attributable to the increased importance of EMEs in world trade. We present the level of imported intermediate goods share in Appendix B, Figure 6.

Figure 4: The Share of Regions in Total Inputs, by Sector (Change)



Note: We present $IIS^{AEs}_{j,t}$, $IIS^{EMEs}_{j,t}$ for selected sectors. The shares are normalized to 1 in 2000 to display the different trends in integration towards two regions. Country classifications follow IMF and details are provided in Appendix A.

and using the same equation, we can calculate the imported intermediate good share for each country/region. Since we aim to compare the relative flattening effects of imports from each region, we standardize each variable around their mean before adding in regressions (leaving out the scaling effects).

Table 3 presents the results. The previous estimation result from total imported intermediate goods shares is shown in column (1). The estimated coefficients from columns (2), (3), and (4) provide the striking difference in the role of integration to the EU, AEs, and EMEs on the UK Phillips curve, respectively. Column (4) shows that the coefficient of the interaction term is negative and statistically significant, implying a role for imported intermediate good shares from EMEs. To state differently, we find that increasing integration of the UK sectors to the EMEs led to a flattening in the UK Phillips curve between 2000 and 2014. On the other hand, columns (2) and (3) suggest that we cannot precisely estimate the role of integration to the EU or AEs on the UK Phillips curve.

To report the economic significance of the results, recall that $IIS^{EME}_{j,t}$ is standardized; thus, the coefficient for the output gap (0.0433) denotes the Phillips curve coef-

Table 3: GVCs and the UK Phillips Curve: Source Matters

2000Q1-2014Q4 Dep Var: $\pi_{j,t}$	(1) Total	(2) EU	(3) AEs	(4) EMEs	(5) EMEs vs. AEs
$(y_{j,t} - y^*_{j,t})$	0.0419***	0.0406***	0.0412***	0.0433***	0.0384***
	(0.0118)	(0.0123)	(0.0124)	(0.00965)	(0.0107)
$IIS_{j,t}$	0.616				
	(0.533)				
$(y_{j,t} - y^*_{j,t}) \times IIS_{j,t}$	-0.0164				
	(0.0197)				
$IIS^{EU}_{j,t}$		0.768			
		(0.668)			
$(y_{j,t} - y^*_{j,t}) \times IIS^{EU}_{j,t}$		-0.00256			
		(0.0169)			
$IIS^{AE}_{j,t}$			0.533		0.353
			(0.603)		(0.619)
$(y_{j,t} - y^*_{j,t}) \times IIS^{AE}_{j,t}$			-0.00746		0.0417*
			(0.0178)		(0.0222)
$IIS^{EME}_{j,t}$				0.445**	0.348
				(0.213)	(0.212)
$(y_{j,t} - y^*_{j,t}) \times IIS^{EME}_{j,t}$				-0.0426***	-0.0735***
				(0.0149)	(0.0202)
Average of Lags	0.373***	0.369***	0.374***	0.365***	0.364***
	(0.0449)	(0.0484)	(0.0453)	(0.0448)	(0.0447)
Industry FE	Y	Y	Y	Y	Y
Time FE	Y	Y	Y	Y	Y
No of Obs.	2158	2158	2158	2158	2158
R^2	0.255	0.256	0.254	0.259	0.261

Note: Results are from Equation 9. Columns (1)-(4) use $IIS_{j,t}$, $IIS^{EU}_{j,t}$, $IIS^{AEs}_{j,t}$, $IIS^{EMEs}_{j,t}$, respectively. Column (5) includes both $IIS^{AEs}_{j,t}$ and $IIS^{EMEs}_{j,t}$ in the regression. Driscoll-Kraay standard errors are in parenthesis with a lag of 8. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

ficient for the mean level of integration to the EMEs. The coefficient of the interaction term (-0.0426) implies that one standard deviation increase in the share of imported intermediate goods from EMEs in UK sectors reduces the slope of the Phillips curve near 0. Furthermore, we apply back-of-the-envelope calculations to understand the importance of rising imported intermediate goods dependence on the EMEs on the value of UK Phillips curve slope. Using the coefficients from column (4), we find that Phillips curve coefficient reduced by 64% between 2000 and 2014 due to rising $IIS^{EME}_{j,t}$, after controlling for aggregate time-varying sector-specific time-invariant effects.

Our findings provide new evidence on the reasons behind the flattening in the UK Phillips curve. Different from previous studies that claim the importance of trade integration on an economy's business cycle, here we argue that the regional direction of the integration affects inflation and economic activity relationships. Comparing the role of integration towards EMEs and other regions, we show that the sources of imports are extremely important to provide a claim on the role of imported intermediate goods dependence on the UK inflation dynamics.

5 Robustness

Here we examine the sensitivity of our estimation results to (a) the role of China in EMEs; (b) the instrumental variable approach; (c) the impact of medium-term forces. We show that our findings are robust.[12]

5.1 Integration to the EMEs: With and Without China

Table 3 has shown that the integration of the UK to the EMEs led to a flattening in the Phillips curve. We now ask whether this result can be attributed to imports from a single EME such as China. To answer this question, we calculate the $IIS^{CH}_{j,t}$ variable using imported intermediate goods from only China for 40 sectors. We also calculate the share of imported intermediate goods from EMEs excluding China as $IIS^{exCH}_{j,t}$.

Estimating Equation 9 using these variables, we present the results in Table 4. Column (1) shows the previous result pointing to the role of integration in the EMEs. Columns (2) and (3) compare the role of rising imported intermediate goods share from China and excluding China on the UK Phillips curve, respectively. The coefficients of interaction terms are close to each other, implying a significant role for both groups. Therefore, we can not claim that the effects of integration to the EMEs are only due to rising dependence on Chinese goods in the UK.

Furthermore, we control for the imported intermediate good prices (from ONS) to isolate the role of increasing imported intermediate good dependence on the slope of the Phillips curve rather than the direct effects on inflation. However, due to data availability, we can focus only on the 18 manufacturing sectors. The results are presented in columns (4-6). The flattening effect of the integration to the EMEs and China is robust to controlling for imported intermediate goods prices, whereas the coefficient of interaction is borderline insignificant for the imports from EMEs excluding China. Since the coefficient (-0.0449) is higher for this group (exCH) compared to the other two groups (-0.0467 for EME and -0.0374 for CH), the insignificance can be due to lower variation in $IIS^{exCH}_{j,t}$ within manufacturing sectors.

[12]We also examine the role of indirect effects of the rising imported intermediate goods dependence on the UK Phillips curve. We find that taking indirect effects into account does not matter for our results both qualitatively and quantitatively. Details of this exercise can be found in Appendix D.

Table 4: EMEs vs China

	Full Sample			Manufacturing Sector		
	(1)	(2)	(3)	(4)	(5)	(6)
	EME	CH	exCH	EME	CH	exCH
$(y_{j,t} - y^*_{j,t})$	0.0433***	0.0438***	0.0449***	0.0961***	0.0796**	0.0929***
	(0.00965)	(0.00980)	(0.0114)	(0.0331)	(0.0384)	(0.0295)
$IIS^{EM}_{j,t}$	0.445**			-0.152		
	(0.213)			(0.272)		
$(y_{j,t} - y^*_{j,t}) \times IIS^{EM}_{j,t}$	-0.0426***			-0.0467***		
	(0.0149)			(0.0143)		
$IIS^{CH}_{j,t}$		0.462***			0.375	
		(0.131)			(0.279)	
$(y_{j,t} - y^*_{j,t}) \times IIS^{CH}_{j,t}$		-0.0415***			-0.0374**	
		(0.0108)			(0.0153)	
$IIS^{exCH}_{j,t}$			-0.0752			-0.272
			(0.276)			(0.323)
$(y_{j,t} - y^*_{j,t}) \times IIS^{exCH}_{j,t}$			-0.0445**			-0.0449
			(0.0221)			(0.0272)
$\pi^M_{j,t}$				0.0226**	0.0220**	0.0222**
				(0.00894)	(0.00892)	(0.00887)
Average of Lags	0.365***	0.360***	0.378***	0.232***	0.230***	0.236***
	(0.0448)	(0.0444)	(0.0427)	(0.0625)	(0.0627)	(0.0629)
Industry FE	Y	Y	Y	Y	Y	Y
Time FE	Y	Y	Y	Y	Y	Y
No of Obs.	2158	2158	2158	802	802	802
R^2	0.259	0.261	0.255	0.266	0.267	0.267

Driscoll-Kraay standard errors are in parenthesis with a lag of 8

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5.2 Instrumental Variable Analysis

Following the trade literature, we assess the potential endogeneity problem due to including the $IIS_{j,t}$ variable in Equation 9 which can affect the interpretation of its role on the flattening of the Phillips curve. In particular, we follow Autor et al. (2013) and argue that import increases might not be due to the increased competitiveness or higher productivity in the source country but also be caused by increasing demand in the importer country. Since higher import demand is correlated with higher inflation, estimations would suffer from endogeneity, and an OLS estimation would understate the actual impact.

We follow Autor et al. (2013) and estimate the following structural equation and

Table 5: Instrumental Variable Analysis

	(EMEs)		(China)	
	(1)	(2)	(3)	(4)
	OLS	IV	OLS	IV
$(y_{j,t} - y^*_{j,t})$	0.0433***	0.0428***	0.0438***	0.0432***
	(0.00965)	(0.0103)	(0.00980)	(0.00948)
$IIS^{EM}_{j,t}$	0.445**	1.125		
	(0.213)	(0.694)		
$(y_{j,t} - y^*_{j,t}) \times IIS^{EM}_{j,t}$	-0.0426***	-0.0498***		
	(0.0149)	(0.0170)		
$IIS^{CH}_{j,t}$			0.462***	0.771***
			(0.131)	(0.199)
$(y_{j,t} - y^*_{j,t}) \times IIS^{CH}_{j,t}$			-0.0415***	-0.0463***
			(0.0108)	(0.0133)
Average of Lags	0.365***	0.358***	0.360***	0.355***
	(0.0448)	(0.0496)	(0.0444)	(0.0465)
First-stage Fstat		1048.6		520.7
Industry FE	Y	Y	Y	Y
Time FE	Y	Y	Y	Y
No of Obs.	2158	2158	2158	2158
R^2	0.259	0.268	0.261	0.266

Driscoll-Kraay standard errors are in parenthesis with a lag of 8

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

the first stage of the IV specification:

$$\pi_{j,t} = \beta_1(y_{j,t} - y^*_{j,t}) + \beta_2 IIS_{j,t} + \beta_3(y_{j,t} - y^*_{j,t}) \times IIS_{j,t} + \beta_4\left(\frac{1}{4}\sum_{j=1}^{4}\pi_{t-j}\right) + \delta_j + \delta_t + \epsilon_{j,t},$$

$$IIS_{j,t} = \alpha IIS^{Others}_{j,t} + \delta_j + \delta_t + \eta_{j,t},$$

where we use the imports of 8 other developed countries from EMEs and China separately to calculate $IIS^{Others}_{j,t} = \frac{\text{Imported Intermediate Goods}^{Others}_{j,t}}{\text{Total Intermediate Goods}_{j,t}}$.[13][14] Here, the identification assumption is that the import demand shocks at the sector level between the UK and 8 other developed countries are independent.[15]

Table 5 shows that the flattening effect of integration with both EMEs (columns (1) and (2)) and China (columns (1) and (2)) are robust to IV estimation. The coefficients on interaction terms are slightly higher (in absolute terms) and statistically significant at 5%.

[13] Australia, Denmark, Finland, Germany, Japan, Spain, Switzerland, United States.

[14] The correlation between the instrument and the endogenous regressor is 0.85.

[15] The results are robust to using G7 countries or only the US for instrumenting the UK's imports.

Table 6: Further Controls on Medium-term Impacts

	(1) Baseline	(2) Lag Variable	(3) Two-Year Moving Average	(4) Three-Year Moving Average
$(y_{j,t} - y^*_{j,t})$	0.0483**	0.0429**	0.0432**	0.0363*
	(0.02130)	(0.02024)	(0.02061)	(0.02080)
$IIS^{EM}_{j,t}$	0.216	0.146	0.158	-0.0672
	(0.2993)	(0.3043)	(0.3326)	(0.3108)
$(y_{j,t} - y^*_{j,t}) \times IIS^{EM}_{j,t}$	-0.0429**	-0.0382**	-0.0402**	-0.0376*
	(0.0163)	(0.0174)	(0.0168)	(0.0201)
Average of Lags	0.379***	0.382***	0.381***	0.426***
	(0.1093)	(0.1121)	(0.1125)	(0.1069)
Industry FE	Y	Y	Y	Y
Time FE	Y	Y	Y	Y
No of Obs.	2158	2030	2030	1877
R^2	0.537	0.536	0.537	0.549

Driscoll-Kraay standard errors are in parenthesis with a lag of 8

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5.3 Further Controls on Medium-term Impacts

Finally, we provide another control on the role of GVC integration following the arguments from Comin and Johnson (2020). They argue that long-lived shocks' impact on trade openness provides a long phase-in dynamics. They also note that a shift in steady states, from a less open to a more open world, would slowly occur over time.

However, our GVC integration measurement is defined at the annual level. To address the potential concern that the role of GVCs from previous periods would also matter for the recent period on inflation dynamics, we use lags of our GVC measurement in our regressions. Furthermore, we calculate the two- and three-year moving average in $IIS^{EM}_{j,t}$ to take into account the medium-term impacts of GVC integration on the Phillips curve relationship.

Table 6 presents the results with a baseline specification (column (1)), using the lag of our GVC measurement $IIS^{EM}_{j,t-1}$ (column (2)), two-year moving average $\frac{IIS^{EM}_{j,t}+IIS^{EM}_{j,t-1}}{2}$, and three-year moving average $\frac{IIS^{EM}_{j,t}+IIS^{EM}_{j,t-1}+IIS^{EM}_{j,t-2}}{3}$. The interaction terms from each column suggest that our results are robust to taking into account the medium-term phase in effects of GVC integration with the EMEs and integration to the EMEs flattens the slope of the UK's Phillips curve.

6 The Role of Medium-Term Forces

While our findings consistently demonstrate the significance of the slope effect of GVCs integration to EMEs on the UK's Phillips curve, it is important to acknowledge that our benchmark results may not be driven only by slope effect, but also influenced by medium-term forces acting as an additional channel. This can provide insights into why our results are specifically applicable to EMEs but not AEs. To understand the importance of the source dimension of GVCs integrations, we use a more general version of the model presented in Section 3.

In particular, the static model we have presented in Section 3 does not answer why our results hold only when the source of GVCs integration is EMEs. According to this model, sectors with higher GVCs integration should have a flatter Phillips Curve. However, our empirical results show that the source of GVC integration also matters. This requires a more general model.

To address this, we extend our static model in two ways. First, we introduce dynamics into our model. This relaxes the assumption of balanced trade in the world economy. Second, we introduce multiple sectors in each economy. This framework is much closer to our empirical framework so can shed results on the importance of source dimension. We outline the details of this model in Appendix F.

GVCs in our Model: Why EMEs? In our framework, GVC integration affects the link between inflation and domestic slack through two distinct channels: Firstly, it exerts a direct impact on the slope, thereby influencing the response of inflation to fluctuations in real economic activity. Secondly, our GVC measure is influenced by movements in terms of trade. Cr Differential prices across countries enable firms to switch between domestic and imported inputs, thereby creating a disconnect between domestic prices and marginal costs.

In our empirical analysis, we use the sum of the nominal value of imported goods from all sectors divided by the value of intermediate goods as our GVC measure. In our model, this corresponds to:

$$GVC_{st} = \frac{n \sum_{s'}^{S} P_{Fs't} M_{Fss't}}{(1-n)\, P^{M}_{st} M_{st}} = \frac{\sum_{s'}^{S} P_{Fs't}(1-\mu_{ss'}) \left(\frac{P_{Fs't}}{P^{M}_{ss't}}\right)^{-\phi_M} \omega_{ss'} \left(\frac{P^{M}_{ss't}}{P^{M}_{st}}\right)^{-\theta_M} M_{st}}{P^{M}_{st} M_{st}},$$

where $M_{Fss't}$ is the imported intermediate good demand of sector s from sector s' at time t, and M_{st} is total intermediate goods demand in sector s. The intermediate input price index is P^{M}_{st} and sectoral intermediates price index, $P^{M}_{ss't}$ is a weighted average of home, $P_{Hs't}$, and foreign, $P_{Fs't}$, sectoral output prices. $\omega_{ss'}$ is the share of sector s' in total intermediate good expenditure of sector s with $\sum_{s'=1}^{S} \omega_{ss'} = 1$. The elasticity of substitution across sectoral intermediate goods is denoted by θ_M. The share of foreign-produced goods at the intermediate level is denoted by $1 - \mu_{ss'}$, and ϕ_M denotes the elasticity of substitution between home and foreign-produced intermediate goods.

In our benchmark model, we discussed how imported intermediate goods share, $1 - \mu$ can make the slope of the Phillips curve flatter. Indeed our GVC measure is a function of μ and increases as the share of imported intermediates increases. However, our measure is also affected by relative prices. This channel is a result of the CES aggregation we used in our framework. With Cobb-Douglas aggregation, when ϕ_{Ms}, the elasticity of substitution between home and foreign-produced intermediate goods in each sector and θ_M, the elasticity of substitution across sectoral intermediate goods are equal to 1, our measure would boil down to:

$$\frac{\sum_{s'}^{S} P_{Fs't} M_{Fss't}}{P_{st}^{M} M_{st}} = \sum_{s'}^{S} \left(1 - \mu_{ss'}\right) \omega_{ss'}.$$

Then the only channel; that our GVC measure captures is the increased openness in production. As shown, the higher the imported intermediate goods share the flatter the Phillips curve. Additionally, with a multi-sector set-up, the higher the input demand from sectors with large import share, the flatter the Phillips curve. However estimates of the elasticity of substitution between home and foreign traded goods vary significantly in the literature and it is far from 1 (e.g., see Feenstra (1994)).

These relative price movements are crucial because the terms of trade directly affect our GVCs measure. The log-linearised version of our GVC measure corresponds to:

$$\widehat{GVC}_{st} = \sum_{s'}^{S} \left(\hat{p}_{Fs't} - \phi_M \left(\hat{p}_{Fs't} - \hat{p}_{ss't}^{M} \right) - \theta_M \left(\hat{p}_{ss't}^{M} - \hat{p}_{st}^{M} \right) + \hat{m}_{st} \right) - \left(\hat{p}_{st}^{M} + \hat{m}_{st} \right),$$

where

$$\hat{p}_{Fs't} - \hat{p}_{ss't}^{M} = \mu_{ss'} \underbrace{\left(\hat{p}_{Fs't} - \hat{p}_{Hs't} \right)}_{tot_{st}}.$$

Intuitively, the relative price channel operates through firms' marginal cost. In our model, the marginal cost is not only a function of wages (or cost of value added) but also domestic and imported intermediate input prices. By log-linearizing the marginal cost presented in Appendix F, Equation F.16 around the steady-state, we obtain:

$$\hat{mc}_{st} = \delta_s \hat{w}_t + (1 - \delta_s) \sum_{s'=1}^{S} \omega_{ss'} [\mu_{ss'} \hat{p}_{Hs't} + (1 - \mu_{ss'}) \hat{p}_{Fs't}] - \hat{a}_t - \hat{a}_{st}. \tag{10}$$

The above expression shows that changes in sectoral marginal cost depend on i) the changes in wages, ii) the changes in domestic input prices, iii) the changes in imported input prices, and iv) the changes in aggregate and sector-specific productivity.[16] When domestic wages increase and the home intermediate goods prices increase relative to the foreign ones, firms can switch towards cheaper imported intermediate inputs as terms of trade improve. This might shed light on why the source of GVC integration matters. It is well-known that business cycles are highly correlated across advanced economies. For instance, Kose et al. (2003) examines the business cycle co-movements across countries and provides empirical evidence on the high degree of synchronization in business cycles among developed economies. This means that, when wages in the UK economy increase, it is likely to also increase in the EU and the US too as output is highly correlated across these countries.

To test this argument thoroughly, we now show the role of business cycle correlations of the UK with the countries that the UK economy has integrated with. We first calculate the business cycle correlation of each country c with the UK (corr(c,UK)) by using HP-filtered real GDP series between 2000Q1 and 2014Q4. Then, we separate countries into low/medium/high correlation groups depending on the correlation coefficients. Using this country classification, we calculate the imported intermediate good share from each group, e.g. the low correlation group country's share in total intermediate goods as $IIS_{j,t}^{Low} = \frac{\text{Imported Intermediate Goods}_{j,t}^{Low}}{\text{Total Intermediate Goods}_{j,t}}$. Appendix A Table 8 displays the business cycle correlation category of each country with the UK.

To compare the role of integration with each group of countries, we estimate Equation 9 using the imported intermediate good share of low and high business cycle correlations groups. Column (1) shows the previous results to compare as a baseline. Columns (2) and (3) present the role of business cycle correlations on the inflation dynamics. The interaction term from Table 7 column (2) suggests that rising imported intermediate goods share from countries with low business cycle correlation leads to a fall in response of inflation to the real economic activity. We do not find a significant role for goods and services imported from countries with high business cycle correlations with the UK (column 3).

Comparing columns (2) and (3) from Table 7, we observe the new evidence that

[16]Note that, under multi-sector, input-output linkages setting increase in the share of imported intermediates (lower $\mu_{ss'}$) not only affect the sectoral marginal cost directly but also indirectly as domestic intermediate input suppliers also use imported intermediates in their production.

Table 7: GVCs and the UK Phillips Curve: Business Cycle Correlations

2000Q1-2014Q4 Dep Var: $\pi_{j,t}$	(1) All	(2) Low BC Corr	(3) High BC Corr
$(y_{j,t} - y^*_{j,t})$	0.0419***	0.0349**	0.0345**
	(0.0118)	(0.0139)	(0.0133)
$IIS_{j,t}$	0.616		
	(0.533)		
$(y_{j,t} - y^*_{j,t}) \times IIS_{j,t}$	-0.0164		
	(0.0197)		
$IIS^{BClow}_{j,t}$		0.338	
		(0.215)	
$(y_{j,t} - y^*_{j,t}) \times IIS^{BClow}_{j,t}$		-0.0251**	
		(0.0121)	
$IIS^{BChigh}_{j,t}$			-0.0144
			(0.228)
$(y_{j,t} - y^*_{j,t}) \times IIS^{BChigh}_{j,t}$			-0.0014
			(0.0098)
Average of Lags	***	***	***
Industry FE	Y	Y	Y
Time FE	Y	Y	Y
No of Obs.	2158	2158	2158
R^2	0.255	0.258	0.251

Driscoll-Kraay standard errors are in parenthesis with a lag of 8
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

not only does the integration of a country to GVCs matter but also the correlation with the business cycle of the integrated country matters. Table 3 suggested a geographical interpretation of the role of GVCs on the flattening of the UK Phillips curve, emphasizing the importance of integrating toward EMEs. On the other hand, Table 7 provides an economic interpretation of the question of why integrating EMEs matters more significantly than AEs. Table 8 shows that the business cycle correlation of the UK economy is lower with EMEs than with AEs. We argue that when the UK economy is integrated into a country with low business cycle correlation, it leads to a decline in pass-through from demand-side shocks to prices. Assume a demand-side shock in the UK that generates a rise in the output gap. The increase in market demand would normally also push the input demand and their costs in the UK. However, if the UK economy is highly integrated with the GVCs, and especially to the countries that have low business cycle correlations with the UK, then firms would switch to the imported intermediate goods (from domestic goods) since these countries have not experienced a rise in their costs and prices due to lack of demand-side shock in that period. Following this shift in input demand of the UK sectors, the change in input costs would be limited. Therefore, we argue that the rise in output prices would also be limited following a demand-side shock in the UK reducing the link between inflation and the domestic demand.

7 Conclusion

In this paper, we studied the impact of GVC integration into EMEs on the inflation dynamics of the UK. Building a model that includes trade in intermediate inputs, we showed analytically that an increased share of imported intermediate goods in production leads to a flatter Phillips curve. Subsequently, leveraging sectoral data we examined the impact of GVC integration on the UK inflation and the output gap relationship. We showed that a rise in imported intermediate goods dependence from EMEs and from countries with low business cycle correlation with the UK implies a flattening in the Phillips curve across various reduced-form specifications.

Our findings have potential implications for understanding the consequences of de-integration from GVCs and related concerns. The interaction between medium-term forces through terms of trade movements and long-term structural shifts through the slope is important for the conduct of monetary policy and is central to understanding the current debate around deglobalisation. We argue that the terms of trade movements is important to understand why we find our results only for EMEs but not for AEs.

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Appendices

A Data

Aggregate Data: Aggregate price, output and unemployment data are from the Office for National Statistics (ONS). We calculate the aggregate output gap using the HP filtering method. Aggregate import and export variables are also from the ONS, and imported intermediate good value is from the World Input-Output Database (WIOD).

Sectoral Data: Sectoral inflation is calculated as a four-quarter percent change in Producer Price Index (PPI) and Service Producer Price Index (SPPI) from ONS. Data has been available at a quarterly frequency since 1997. The sectoral output series, Index of Production (IoP), and Index of Services (IoS) are also from ONS. Data has been available at a quarterly frequency since 1995 (1997 for the service sectors). Sectoral output gap series is calculated as the deviation indexes from their HP-filtered trends separately.

World Input-Output Database (WIOD): We use the last version (2016) of the WIOD to calculate imports, exports, and imported intermediate good values for 56 sectors at an annual frequency from 2000 to 2014. However, the sectoral aggregation from WIOD does not match the aggregation level of sectoral price and output data from ONS. Therefore, we use many-to-many matching using the weights from Blue Book GDP Source Catalogue. **Country Coverage:** Following the IMF classification, we consider Brazil, Hungary, China, India, Indonesia, Mexico, Poland, Romania, Russia and Turkey as EMEs; Austria, Belgium, Czech Republic, Cyprus, Germany, Denmark, Spain, Estonia, Finland, France, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Latvia, Luxembourg, Malta, the Netherlands, Norway, Poland, Romania, Slovakia, Slovenia and Sweden as the EU and Australia, Canada, South Korea, Japan, US, Switzerland and the EU excluding Poland, Hungary and Romania as AEs.

Business cycle correlations: We use OECD country-level real GDP growth statistics to calculate business correlations between countries and the UK.

Table 8: Business Cycle Categories

Low Business Cycle Correlation		High Business Cycle Correlation	
Country	$corr(y^{UK}, y^{C})$	Country	$corr(y^{UK}, y^{C})$
Croatia	0.648	Estonia	0.832
Chile	0.642	United States	0.831
Slovenia	0.640	Japan	0.803
Slovakia	0.614	Latvia	0.801
Argentina	0.597	Lithuania	0.799
Korea	0.571	Hungary	0.787
Netherlands	0.565	Denmark	0.779
Norway	0.563	Mexico	0.768
Spain	0.557	Sweden	0.768
Iceland	0.547	South Africa	0.767
Israel	0.481	Belgium	0.749
New Zealand	0.456	Colombia	0.743
Bulgaria	0.441	Luxembourg	0.735
Ireland	0.429	Germany	0.730
Roumania	0.410	France	0.724
Australia	0.386	Russia	0.706
Portugal	0.289	Canada	0.699
Indonesia	0.260	Switzerland	0.686
Greece	0.251	Finland	0.685
Brazil	0.217	Turkey	0.676
Poland	0.210	Czech Republic	0.675
Saudi Arabia	-0.079	Austria	0.672
India	-0.490	Italy	0.651
Mean	0.401	Mean	0.742
Median	0.456	Median	0.743

Note: Sample period is between 2000Q1 and 2014Q4 (matching the main empirical analysis period). Data is from OECD.

B Additional Figures

Figure 5: Change in IIS across other countries

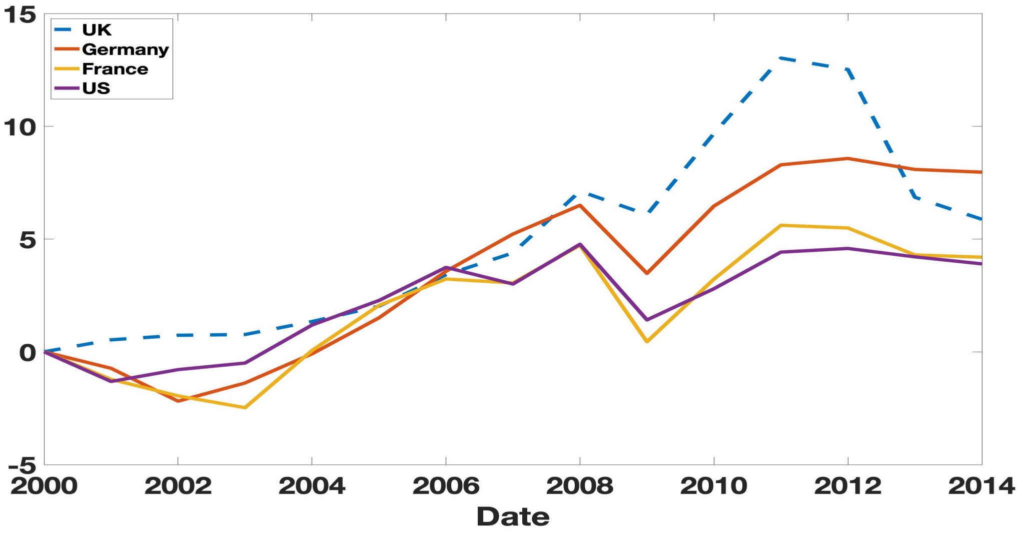


Figure 6: Share of Regions in Total Inputs by Sectors

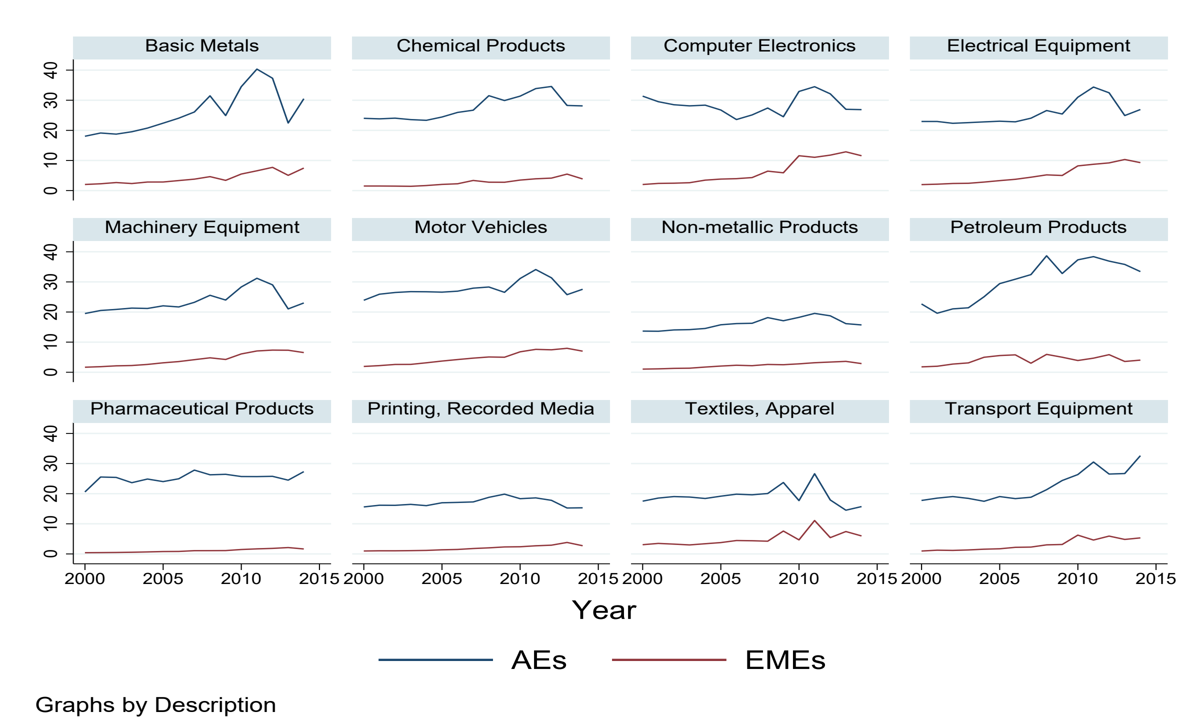
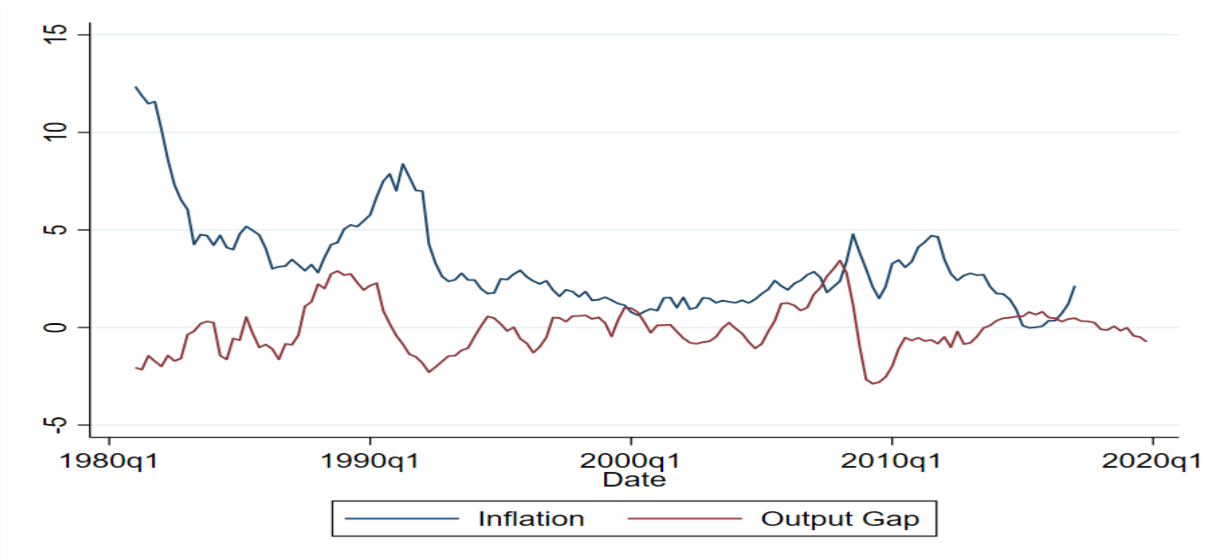


Figure 7: Aggregate Inflation and Output Gap



Note: Aggregate inflation is from ONS and the output gap is the deviation of real GDP from its HP-filtered trend.

C The Role of Trade

Here we explore the role of openness in the flattening of the UK's Phillips curve. We begin by displaying the trade openness and total import share over time (Figure 8) since the 1950s. Trade openness almost doubled from the mid-1980s to 2000 and then further increased by 50% from 2000 to 2020. Analogously, the share of imports doubled between the 1950s and 2010, remaining stable after that.

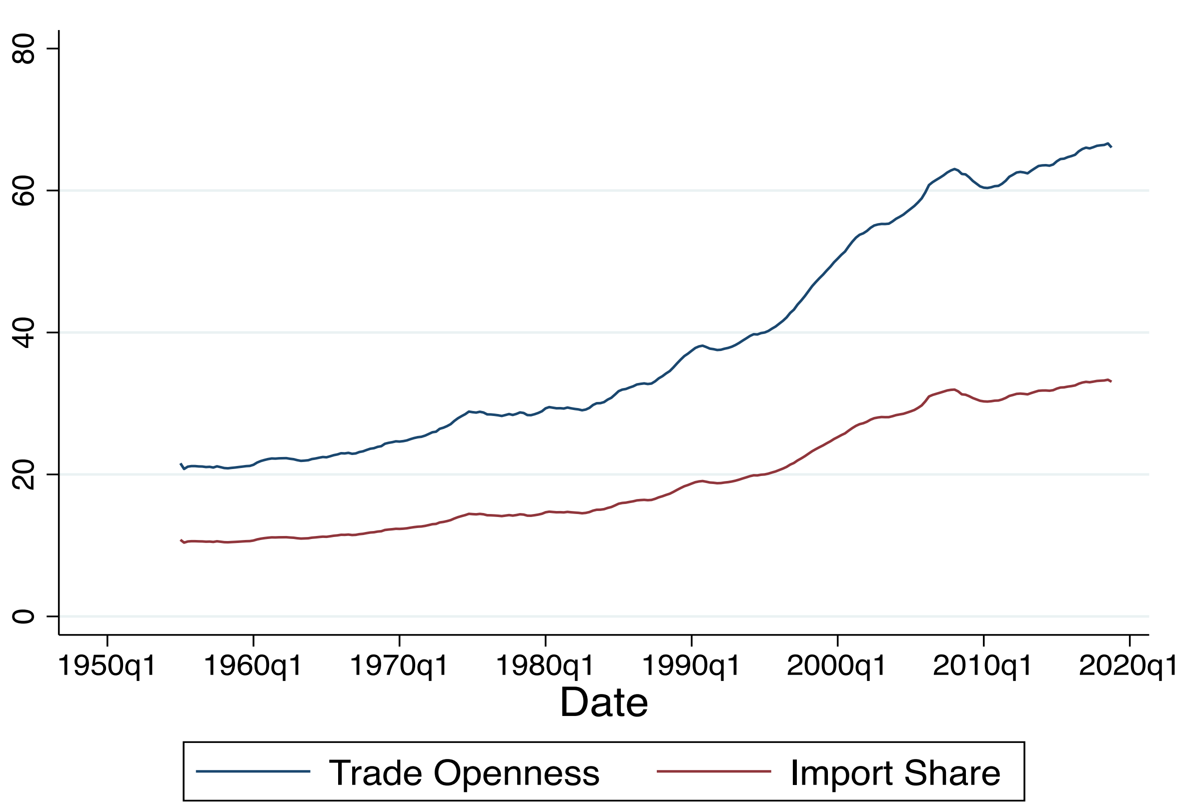
Both measures from Figure 8 point to a significantly increasing integration of the UK economy in global markets. We argue that increasing trade openness makes the prices in the UK economy less dependent on domestic factors. Therefore, the relationship between inflation and domestic economic activity weakens. To test this argument, we follow Ball (2006) and estimate the following regression where we interact aggregate output gap with trade openness

$$\pi_t = \beta_1 (y_t - y_t^*) + \beta_2 \text{Openness}_t + \beta_3 (y_t - y_t^*) \times \text{Openness}_t + \beta_4 \pi_t^M + \beta_5 \pi_t^{oil} + \beta_6 \left(\frac{1}{4} \sum_{j=1}^{4} \pi_{t-j} \right) + \varepsilon_t \tag{C.1}$$

where $\text{Openness}_t = \frac{\text{Imports+Exports}}{\text{Real GDP}}$. This variable is standardized (around the mean) to ease the interpretation of the estimated coefficients. Previously, we have shown a positive relationship between inflation and the output gap. In this exercise, we are interested in the estimation of the interaction parameter, β_3.

Table 9 column (1) suggests that the coefficients attached to $(y_t - y_t^*) \times \text{Openness}_t$ is negative and statistically significant, supporting the argument that rising trade

Figure 8: Trade openness



Note: Trade Openness: $\frac{\text{Imports+Exports}}{\text{Real GDP}}$ and Import Share: $\frac{\text{Imports}}{\text{Real GDP}}$ using ONS data.

openness in the UK led to a flattening in the Phillips curve. Recall that, Openness$_t$ is standardized, thus β_1 coefficient denotes the Phillips curve slope for the mean trade openness period (e.g., the mid-1990s) in our sample and the coefficient for the interaction term (β_3) represents the effect of a one standard deviation increase in trade openness on the slope of the Phillips curve. Noting that one standard deviation increase in trade openness corresponds to the beginning of the 2000s (compared to the mid-1990s) in our sample, the reduced-form estimation results provide a significant role for trade in explaining the large drop in the Phillips curve coefficient around the same period in Figure 1a.

As a robustness check, we control the role of the inflation targeting regime in 1992 and central bank independence in 1997. We include a dummy variable equal to 1 after 1992 ($Post_{1992}$) and another one after 1997 ($Post_{1997}$) to control separately for the possible effects of these two policies. Columns (2) and (3) show that the results remain qualitatively unchanged, implying that one standard deviation increase in the trade variable flattens the slope of the Phillips curve to roughly 0.1.

The results imply that openness may be an important driver behind the flattening of the UK Phillips curve.

Table 9: Trade and the UK Phillips Curve
(1980Q1-2017Q1)

π_t	(1)	(2)	(3)
$(y_t - y_t^*)$	0.427***	0.426***	0.429***
	(0.0934)	(0.0936)	(0.0952)
Openness$_t$	0.00983	0.0804	0.238
	(0.0563)	(0.120)	(0.212)
$(y_t - y_t^*) \times$ Openness$_t$	-0.315***	-0.316***	-0.319***
	(0.0870)	(0.0883)	(0.0892)
π_t^{oil}	0.0104*	0.0104*	0.0107*
	(0.00593)	(0.00589)	(0.00588)
π_t^M	0.0498***	0.0500***	0.0489***
	(0.0179)	(0.0173)	(0.0176)
$\frac{1}{4}\sum_{j=1}^{4}\pi_{t-j}$	0.913***	0.918***	0.924***
	(0.0241)	(0.0274)	(0.0272)
Observations	149	149	149
R^2	0.9674	0.9675	0.9677
$Post_{1992}$	No	Yes	No
$Post_{1997}$	No	No	Yes

Newey-West standard errors in parentheses with a lag of 18
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

D Indirect Effects

We examine the sensitivity of our results to the indirect effects of the rise in imported intermediate goods in production on the UK Phillips curve. The benchmark results documented the "direct" effects of the GVCs on the Phillips curve. However, a growing literature shows how a shock to one industry can propagate to other industries through sectoral linkages and generate more amplified effects on the aggregate economy. This subsection examines the role of amplified (direct+indirect) effects using input-output tables.

Let's rename the variable $IIS_{j,t}$ from Equation (2) as the direct effects of the GVCs on industry j. Previous results showed that the inflation and output gap relationship is weaker in industries with higher imported intermediate goods dependence. This result also implies that the rigidity in output prices of an industry j will also be experienced by other industries that use goods/services from industry j as intermediate goods. Thus, the direct effects of $IIS_{j,t}$ to industry j propagates indirectly to its buyers. I define "Indirect effects" following Acemoglu et al. (2016) as

$$IIS_{j,t}^{Ind} = \sum_{g} \omega_{gj} IIS_{gt}, \tag{D.1}$$

which is equal to the weighted average of directly imported intermediate good shares (IIS_{gt}) across all industries, indexed by g, that *supply* goods to the industry j. The weights ω_{gj} are defined as

$$\omega_{gj} = \frac{\mu_{gj}}{\sum\limits_{g'} \mu_{g'j}}, \tag{D.2}$$

where μ_{gj} is the value of inputs used by industry j from industry g, and calculated using 2000 ONS UK input-output tables. The weight ω_{gj} in Equation (D.2) is the share of inputs from industry g in total inputs used by industry j.

I also note that the imported intermediate good dependence of industry j affects other industries (g). Then, an affected industry g would further affect industry j and so on. To take into account the full chain of effects, I use the Leontief inverse of the linkages from weights of Equation (D.2) following Acemoglu et al. (2016). Thus, the total effects from GVC integration is measured using Leontief inverse matrices of weights such that

$$IIS^{Total}_{j,t} = \sum\limits_{g} \omega^L_{gj} IIS_{gt}, \tag{D.3}$$

where ω^L_{gj} are the weights adjusted by Leontief inverses.

The intuition for the indirect effects is that when an industry j's suppliers experience a high imported intermediate good dependence from abroad, then the industry j's inputs would be further dependent on imported goods and services. Therefore, we argue that this channel would further weaken the sensitivity of "output" prices against a change in economic activity as the input costs would be dependent abroad.

Note that Equation (D.3) generates a general formula to calculate the total effects of imported intermediate goods share. Thus, we focus on generating total effects for our two main results separately: Role of EMEs and low business cycle correlation countries[17].

Table (10) presents the results from the estimation of specification (9) using both direct and total effects. Comparison of the interaction terms between columns (1) and (2), and (3) and (4) cannot confirm the amplification of the GVCs' role through sectoral linkages. The interaction terms are negative and significant in each specification, but the coefficients are not different when total effects through sectoral linkages are used. Thus, the results suggest no evidence of the role of sectoral linkages amplifying the previous results.

[17]We calculate $IIS^{EM,Total}_{j,t} = \sum\limits_{g} \omega^L_{gj} IIS_{gt}$ and $IIS^{BClow,Total}_{j,t} = \sum\limits_{g} \omega^L_{gj} IIS_{gt}$ separately and use in our regressions

Table 10: Indirect Effects

	(EMEs)		(Low BC Corr.)	
	(1)	(2)	(3)	(4)
	Direct	Total	Direct	Total
$(y_{j,t} - y^*_{j,t})$	0.0483^{**}	0.0490^{**}	0.430^{***}	0.0443^{***}
	(0.02130)	(0.02140)	(0.01013)	(0.00994)
$IIS^{EM}_{j,t}$	0.216			
	(0.2993)			
$(y_{j,t} - y^*_{j,t}) \times IIS^{EM}_{j,t}$	-0.0429^{**}			
	(0.0163)			
$IIS^{EM,Total}_{j,t}$		0.231		
		(0.2939)		
$(y_{j,t} - y^*_{j,t}) \times IIS^{EM,Total}_{j,t}$		-0.0410^{**}		
		(0.0159)		
$IIS^{BClow}_{j,t}$			0.552^{***}	
			(0.18623)	
$(y_{j,t} - y^*_{j,t}) \times IIS^{BClow}_{j,t}$			-0.0258^{**}	
			(0.01145)	
$IIS^{BClow,Total}_{j,t}$				0.563^{***}
				(0.18868)
$(y_{j,t} - y^*_{j,t}) \times IIS^{BClow,Total}_{j,t}$				-0.0269^{**}
				(0.01139)
Average of Lags	0.379^{***}	0.379^{***}	0.364^{***}	0.364^{***}
	(0.1093)	(0.1092)	(0.0445)	(0.0447)
Industry FE	Y	Y	Y	Y
Time FE	Y	Y	Y	Y
No of Obs.	2158	2158	2158	2158
R^2	0.537	0.537	0.561	0.561

Driscoll-Kraay standard errors are in parenthesis with a lag of 8

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

E Static Model Proofs

Proof of Proposition 1. The marginal cost can be written as

$$\log MC = \delta \log W + (1-\delta) \log P^M - \log A,$$
$$\log MC^* = \delta^* \log W^* + (1-\delta^*) \log P^{M*} - \log A^*.$$

The input price index can be written as

$$\log P^M = \mu \log P_H + (1-\mu) \log P_F,$$
$$\log P^{M*} = \mu^* \log P^*_F + (1-\mu^*) \log P^*_H,$$

Combining the last two expressions yield

$$\log MC = \delta \log W + (1-\delta)(\mu \log P_H + (1-\mu)\log P_F) - \log A,$$
$$\log MC^* = \delta^* \log W^* + (1-\delta^*)(\mu \log P_F^* + (1-\mu)\log P_H^*) - \log A^*,$$

Under producer currency pricing, we have

$$\log P_F = \log P_F^* + \log \mathcal{E},$$
$$\log P_H = \log P_H^* + \log \mathcal{E},$$

where $\mathcal{E}$ is the nominal exchange rate (units of foreign currency in home currency). Plugging in PCP yields

$$\log MC = \delta \log W + (1-\delta)(\mu \log P_H + (1-\mu)\log P_F^* + (1-\mu)\log \mathcal{E}) - \log A,$$
$$\log MC^* = \delta \log W^* + (1-\delta)(\mu^* \log P_F^* + (1-\mu^*)\log P_F - (1-\mu)\log \mathcal{E}) - \log A^*.$$

In matrix notation, we can write the previous equation as

$$\log \mathbf{MC} = \delta \cdot \log \mathbf{W} + \Omega \log \mathbf{p} + (\mathbf{1}-\delta) \cdot \begin{pmatrix} 1-\mu \\ -(1-\mu^*) \end{pmatrix} \log \mathcal{E} - \log \mathbf{A}, \tag{E.1}$$

where $\log \boldsymbol{MC} = \begin{pmatrix} \log MC \\ \log MC^* \end{pmatrix}$. With nominal rigidities, domestic inflation is given by

$$d \log \mathbf{p} = \Theta d \log \mathbf{MC}, \tag{E.2}$$

where $\Theta = diag(1-\theta, 1-\theta^*)$. Plugging in this expression to a differenced version of (E.1), we get

$$d \log \mathbf{MC} = \delta \cdot d \log \mathbf{W} + \Omega\Theta d \log \mathbf{MC} + (\mathbf{1}-\delta) \cdot \begin{pmatrix} 1-\mu \\ -(1-\mu^*) \end{pmatrix} d \log \mathcal{E} - d \log \mathbf{A}.$$

Rearranging for marginal cost yields

$$d \log \mathbf{MC} = (1-\Omega\Theta)^{-1} \left(\delta \cdot d \log \mathbf{W} + (\mathbf{1}-\delta) \cdot \begin{pmatrix} 1-\mu \\ -(1-\mu^*) \end{pmatrix} d \log \mathcal{E} - d \log \mathbf{A} \right),$$

where the term $(I-\Omega\Theta)^{-1}$ captures the 'adjusted' Leontief inverse as in Rubbo (2020) - the production network structure of the economy, suitably adjusted for nominal rigidities. Plugging the previous equation into (E.2) yields

$$d \log \mathbf{p} = \Theta(1-\Omega\Theta)^{-1}\left(\delta \cdot d\log \mathbf{W} + (\mathbf{1}-\delta)\cdot \begin{pmatrix} 1-\mu \\ -(1-\mu^*) \end{pmatrix} d\log \mathcal{E} - d\log \mathbf{A}\right). \tag{E.3}$$

CPI inflation can be written as

$$d\log \mathbf{P} = \Phi d\log \mathbf{p} + \begin{pmatrix} 1-\alpha \\ -(1-\alpha^*) \end{pmatrix} d\log \mathcal{E}, \tag{E.4}$$

where

$$\log \mathbf{P} = \begin{pmatrix} \log P \\ \log P^* \end{pmatrix}, \qquad \Phi = \begin{pmatrix} \alpha & 1-\alpha \\ 1-\alpha^* & \alpha^* \end{pmatrix}.$$

Market Clearing

Now we write the Phillips Curve in terms of output gaps in home and foreign. Market clearing ensures that

$$Y_H = C_H + M_H + \frac{1-n}{n}\left(C_H^* + M_H^*\right), \tag{E.5}$$

$$Y_F^* = C_F^* + M_F^* + \frac{n}{1-n}\left(C_F + M_F\right). \tag{E.6}$$

We assume that there is balanced trade in final and intermediate goods [18]

$$nP_F(C_F + M_F) = (1-n)P_H(C_H^* + M_H^*), \tag{E.7}$$

and this allows us to write the market clearing (E.5) as

$$Y_H^{VA} \equiv Y_H - M_H - \frac{P_F}{P_H}M_F = C_H + \frac{P_F}{P_H}C_F, \tag{E.8}$$

where we define the value-added output as gross output less intermediate goods, both domestic and imported. We can then rewrite the previous equation to get the real consumption in terms of real value-added

$$P_H Y_H^{VA} = P_H C_H + P_F C_F = PC \iff C = \frac{P_H}{P}Y_H^{VA}, \tag{E.9}$$

[18]Imposing this condition implies that the country size parameter no longer appears in the derivation below. However, the share parameters α and μ capture an equivalent notion.

Similarly, we can write foreign consumption in terms of foreign value added.

$$Y_F^{*VA} \equiv Y_F^* - M_F^* - \frac{P_H^*}{P_F^*} M_H^* = C_F^* + \frac{P_H^*}{P_F^*} C_H^*, \tag{E.10}$$

where the relative price follows from PCP. As above, we can rewrite the previous equation as

$$P_F^* Y_F^{*VA} = P_F^* C_F^* + P_H^* C_H^* = P^* C^* \iff C^* = \frac{P_F^*}{P^*} Y_F^{*VA}. \tag{E.11}$$

From the intra-temporal equation, we have

$$\begin{aligned} d\log W &= d\log P + \sigma d\log C + \varphi d\log L \\ &= \sigma d\log Y_H^{VA} + \varphi d\log L + \sigma(d\log P_H - d\log P), \end{aligned}$$

where the last equality follows (E.8). Similarly for the foreign economy,

$$d\log W^* - d\log P^* = \sigma d\log Y_F^{*VA} + \varphi d\log L^* + \sigma(d\log P_F^* - d\log P^*).$$

Now we write the previous two expressions in terms of the output gap. Using the definition of the output gap, we have

$$\begin{aligned} d\log W - d\log P &= \sigma(\tilde{y}_H + y_H^{nat}) + \varphi d\log L + \sigma(d\log P_H - d\log P) \\ &= \sigma\tilde{y}_H + \sigma y_H^{nat} + \varphi d\log L + \sigma(d\log P_H - d\log P). \end{aligned} \tag{E.12}$$

Part of the right-hand side is equal to

$$\begin{aligned} \sigma y_H^{nat} + \varphi d\log L &= \sigma y_H^{nat} + \varphi(d\log L - d\log L^{nat}) + \varphi d\log L^{nat} \\ &= \sigma y_H^{nat} + \varphi\tilde{y}_H + \varphi d\log L^{nat}, \end{aligned}$$

where the last equation follows from the equation $Y = AL$, since labour is the only factor of production. Continuing, we have

$$\begin{aligned} \sigma y_H^{nat} + \varphi d\log L &= \sigma(d\log L^{nat} + d\log A) + \varphi\tilde{y}_H + \varphi d\log L^{nat} \\ &= \varphi\tilde{y}_H + \sigma d\log A + (\sigma+\varphi) d\log L^{nat}. \end{aligned}$$

By Lemma 6 of Rubbo (2020)

$$d\log L^{nat} = \frac{1-\sigma}{\sigma+\varphi} d\log A, \tag{E.13}$$

hence

$$\begin{aligned}\sigma y_H^{nat} + \varphi d\log L &= \varphi \tilde{y}_H + \sigma d\log A + (\sigma+\varphi)\frac{1-\sigma}{\sigma+\varphi} d\log A \\ &= \varphi \tilde{y}_H + d\log A.\end{aligned} \tag{E.14}$$

Plugging the last equation into (E.12), we get

$$d\log W - d\log P + (\sigma+\varphi)\tilde{y}_H + d\log A + \sigma(d\log P_H - d\log P). \tag{E.15}$$

A similar expression can be derived for the foreign economy. Hence, in matrix form, we have

$$d\log \mathbf{W} - d\log \mathbf{P} = (\sigma+\varphi)\tilde{y} + d\log A + \sigma(d\log \mathbf{P} - d\log \mathbf{p}), \tag{E.16}$$

where $\tilde{y} = \begin{pmatrix} \tilde{y}_H \\ \tilde{y}_F^* \end{pmatrix}$. The last term of the previous equation is

$$\sigma(d\log \mathbf{P} - d\log \mathbf{p}) = \left(\sigma(I-\Phi)d\log \mathbf{p} - \begin{pmatrix} 1-\alpha \\ -(1-\alpha^*) \end{pmatrix} d\log \mathcal{E}\right). \tag{E.17}$$

Hence we can rewrite (E.16) as

$$d\log \mathbf{W} - d\log \mathbf{P} = (\sigma+\varphi)\tilde{y} + d\log \mathbf{A} + \sigma(I-\Phi)d\log \mathbf{p} - \sigma \begin{pmatrix} 1-\alpha \\ -(1-\alpha^*) \end{pmatrix} d\log \mathcal{E}. \tag{E.18}$$

Using (E.4), we can also write

$$d\log \mathbf{W} - d\log \mathbf{P} = d\log \mathbf{W} - \Phi d\log \mathbf{p} - \begin{pmatrix} 1-\alpha \\ -(1-\alpha^*) \end{pmatrix} d\log \mathcal{E}. \tag{E.19}$$

Plug in for $d\log \mathbf{p}$ using (E.3), we get

$$\begin{aligned} d\log \mathbf{W} - d\log \mathbf{P} = d\log \mathbf{W} - \Phi\Theta(I-\Omega\Theta)^{-1} & \\ \left[\delta \cdot d\log \mathbf{W} + (1-\delta)\cdot \begin{pmatrix} 1-\mu \\ -(1-\mu^*) \end{pmatrix} d\log \mathcal{E} - d\log \mathbf{A}\right] & \\ - \begin{pmatrix} 1-\alpha \\ -(1-\alpha^*) \end{pmatrix} d\log \mathcal{E}. & \end{aligned} \tag{E.20}$$

Expand and collect

$$d\log \mathbf{W} - d\log \mathbf{P} = \left[I - \Phi\Theta(I-\Omega\Theta)^{-1}\delta\right] d\log \mathbf{W} + \Phi\Theta(I-\Omega\Theta)^{-1} d\log \mathbf{A}$$
$$- \left[\Phi\Omega(I-\Omega\Theta)^{-1}(\mathbf{1}-\delta)\cdot\begin{pmatrix}1-\mu\\-(1-\mu^*)\end{pmatrix} + \begin{pmatrix}1-\alpha\\-(1-\alpha^*)\end{pmatrix}\right] d\log \mathcal{E}. \tag{E.21}$$

Combine (E.18) and (E.21)

$$(\sigma+\varphi)\widetilde{y} + \sigma(I-\Phi)d\log \mathbf{p} - \sigma\begin{pmatrix}1-\alpha\\-(1-\alpha^*)\end{pmatrix} d\log\mathcal{E} = \left[I - \Phi\Theta(I-\Omega\Theta)^{-1}\delta\right] d\log \mathbf{W}$$
$$+ \Phi\Theta(I-\Omega\Theta)^{-1} d\log \mathbf{A}$$
$$- \left[\Phi\Theta(I-\Omega\Theta)^{-1}(\mathbf{1}-\delta)\cdot\begin{pmatrix}1-\mu\\-(1-\mu^*)\end{pmatrix} + \begin{pmatrix}1-\alpha\\-(1-\alpha^*)\end{pmatrix}\right] d\log \mathcal{E}. \tag{E.22}$$

Collect terms

$$\begin{aligned}
&(\sigma+\varphi)\widetilde{y} + \left[I - \Phi\Theta(I-\Omega\Theta)^{-1}\right] d\log \mathbf{A} \\
&+ \left[\Phi\Theta(I-\Omega\Theta)^{-1}(\mathbf{1}-\delta)\cdot\begin{pmatrix}1-\mu\\-(1-\mu^*)\end{pmatrix} + (1-\sigma)\begin{pmatrix}1-\alpha\\-(1-\alpha^*)\end{pmatrix}\right] d\log \mathcal{E} \\
&+ \sigma(I-\Phi)d\log \mathbf{p} = [I - \Phi\Theta(I-\Omega\Theta)^{-1}\delta] d\log \mathbf{W}.
\end{aligned} \tag{E.23}$$

Plug in for $d\log \mathbf{p}$ using (E.3)

$$\begin{aligned}
&(\sigma+\varphi)\widetilde{y} + [I - \Phi\Theta(I-\Omega\Theta)^{-1}] d\log \mathbf{A} \\
&+ \left[\Phi\Theta(I-\Omega\Theta)^{-1}(\mathbf{1}-\delta)\cdot\begin{pmatrix}1-\mu\\-(1-\mu^*)\end{pmatrix} + (1-\sigma)\begin{pmatrix}1-\alpha\\-(1-\alpha^*)\end{pmatrix}\right. \\
&\left. + \sigma(I-\Phi)\Theta(I-\Omega\Theta)^{-1}(\mathbf{1}-\delta)\cdot\begin{pmatrix}1-\mu\\-(1-\mu^*)\end{pmatrix} d\log \mathcal{E}\right. \\
&= \left[I - \Phi\Theta(I-\Omega\Theta)^{-1}\delta - \sigma(I-\Phi)\Theta(I-\Omega\Theta)^{-1}\delta\right] d\log \mathbf{W}.
\end{aligned} \tag{E.24}$$

Collect terms

$$
\begin{aligned}
&(\sigma+\varphi)\widetilde{y}+\Big[I-\Phi\Theta(I-\Omega\Theta)^{-1}-\sigma(I-\Phi)\Theta(I-\Omega\Theta)\Big]\,d\log\mathbf{A} \\
&+\Bigg[\Phi\Theta(I-\Omega\Theta)^{-1}(\mathbf{1}-\delta)\cdot\begin{pmatrix}1-\mu\\-(1-\mu^*)\end{pmatrix}+(1-\sigma)\begin{pmatrix}1-\alpha\\-(1-\alpha^*)\end{pmatrix} \\
&+\sigma(I-\Phi)\Theta(I-\Omega\Theta)^{-1}(\mathbf{1}-\delta)\cdot\begin{pmatrix}1-\mu\\-(1-\mu^*)\end{pmatrix}d\log\mathcal{E} \\
&=\Big[I-\Phi\Theta(I-\Omega\Theta)^{-1}\delta-\sigma(I-\Phi)\Theta(I-\Omega\Theta)^{-1}\delta\Big]\,d\log\mathbf{W}.
\end{aligned}
\tag{E.25}
$$

Simplify

$$
\begin{aligned}
&(\sigma+\varphi)\widetilde{y}+\Big[I-((1-\sigma)I+\sigma\Phi)\Theta(I-\Omega\Theta)^{-1}\Big]\,d\log\mathbf{A} \\
&+\Bigg[((1-\sigma)I-\sigma\Phi)\Theta(I-\Omega\Theta)^{-1}(\mathbf{1}-\delta)\cdot\begin{pmatrix}1-\mu\\-(1-\mu^*)\end{pmatrix}+(1-\sigma)\begin{pmatrix}1-\alpha\\-(1-\alpha^*)\end{pmatrix}\Bigg]\,d\log\mathcal{E} \\
&=[I-((1+\sigma)\Phi-\sigma I)\Theta(I-\Omega\Theta)^{-1}\delta]d\log\mathbf{W}.
\end{aligned}
\tag{E.26}
$$

Rearrange for $d\log\mathbf{W}$

$$
\begin{aligned}
d\log\mathbf{W}&=[I-((1+\sigma)I+\sigma\Phi)\Theta(I-\Omega\Theta)^{-1}\delta]^{-1} \\
&[(\sigma+\varphi)\widetilde{y}+[I-[(1-\sigma)I+\sigma\Phi]\Theta(I-\Omega\Theta)^{-1}]d\log\bar{A} \\
&+\Bigg[((1-\sigma)I-\sigma\Phi)\Theta(I-\Omega\Theta)^{-1}(\mathbf{1}-\delta)\cdot\begin{pmatrix}1-\mu\\-(1-\mu^*)\end{pmatrix}+(1-\sigma)\begin{pmatrix}1-\alpha\\-(1-\alpha^*)\end{pmatrix}\Bigg]\,d\log\mathcal{E}.
\end{aligned}
\tag{E.27}
$$

Plug back into (E.3)

$$
\begin{aligned}
d\log\mathbf{p}=\Theta(I-\Omega\Theta)^{-1}\delta\Bigg(&[I-((1+\sigma)\Phi-\sigma I)\Theta(I-\Omega\Theta)^{-1}\delta]^{-1} \\
&\Bigg\{(\sigma+\varphi)\widetilde{y}+\Big[I-((1-\sigma)I+\sigma\Phi)\Theta(I-\Omega\Theta)^{-1}\Big]\,d\log\mathbf{A} \\
&+\Bigg[((1-\sigma)I-\sigma\Phi)\Theta(I-\Omega\Theta)^{-1}(1-\delta)\begin{pmatrix}1-\mu\\-(1-\mu^*)\end{pmatrix}+(1-\sigma)\begin{pmatrix}1-\alpha\\-(1-\alpha^*\end{pmatrix}\Bigg]\,d\log\mathcal{E}\Bigg\}\Bigg) \\
&+\Theta(I-\Omega\Theta)^{-1}\Bigg[(\mathbf{1}-\delta)\cdot\begin{pmatrix}1-\mu\\-(1-\mu^*)\end{pmatrix}d\log\mathcal{E}-d\log\mathbf{A}\Bigg].
\end{aligned}
\tag{E.28}
$$

Collect terms

$$
\begin{aligned}
& d\log \mathbf{p} = \Theta(I-\Omega\Theta)^{-1}\delta \\
& \left[I-((1+\sigma)\Phi-\sigma I)\Theta(I-\Omega\Theta)^{-1}\delta\right]^{-1}(\sigma+\varphi)\widetilde{y} \\
& + \Bigg[\Theta(I-\Omega\Theta)^{-1}\delta[I-((1+\sigma)\Phi-\sigma I)\Omega(I-\Omega\Theta)^{-1}\delta]^{-1}[I-((1-\sigma)I\sigma\Phi)\Theta(I-\Omega\Theta)^{-1}] \\
& - \Theta(I-\Omega\Theta)^{-1}\Bigg] d\log \mathbf{A} \\
& + \Bigg[\Theta(I-\Omega\Theta)^{-1}\delta[I-((1+\sigma)\Phi-\sigma I)\Theta(I-\Omega\Theta)^{-1}\delta]^{-1} \\
& \left\{((1+\sigma)I-\sigma\Phi)\Theta(I-\Omega\Theta)^{-1}(1-\delta)\begin{pmatrix}1-\mu\\-(1-\mu^*)\end{pmatrix}+(1-\sigma)\begin{pmatrix}1-\alpha\\-(1-\alpha^*)\end{pmatrix}\right\} \\
& + \Theta(I-\Omega\Theta)^{-1}(\mathbf{1}-\delta)\cdot\begin{pmatrix}1-\mu\\-(1-\mu^*)\end{pmatrix}\Bigg] d\log\mathcal{E}.
\end{aligned}
\tag{E.29}
$$

Use (E.4) to get CPI Phillips Curves

$$
\begin{aligned}
& d\log \mathbf{P} = \Phi\Theta(I-\Omega\Theta)^{-1}\delta\left[I-((1+\sigma)\Phi-\sigma I)\Theta(I-\Omega\Theta)^{-1}\delta\right]^{-1}(\sigma+\varphi)\widetilde{y} \\
& + \Phi\Bigg[\Theta(I-\Omega\Theta)^{-1}\delta[I-((1+\sigma)\Phi-\sigma I)\Omega(I-\Omega\Theta)^{-1}\delta]^{-1}[I-((1-\sigma)I+\sigma\Phi)\Theta(I-\Omega\Theta)^{-1}] \\
& - \Theta(I-\Omega\Theta)^{-1}\Bigg] d\log \mathbf{A} \\
& + \Phi\Bigg[\Theta(I-\Omega\Theta)^{-1}\delta[I-((1+\sigma)\Phi-\sigma I)\Theta(I-\Omega\Theta)^{-1}\delta]^{-1} \\
& \left\{((1+\sigma)I-\sigma\Phi)\Theta(I-\Omega\Theta)^{-1}(\mathbf{1}-\delta)\cdot\begin{pmatrix}1-\mu\\-(1-\mu^*)\end{pmatrix}+(1-\sigma)\begin{pmatrix}1-\alpha\\-(1-\alpha^*)\end{pmatrix}\right\} \\
& + \Theta(I-\Omega\Theta)^{-1}(\mathbf{1}-\delta)\cdot\begin{pmatrix}1-\mu\\-(1-\mu^*)\end{pmatrix}\begin{pmatrix}1-\alpha\\-(1-\alpha^*)\end{pmatrix}\Bigg] d\log\mathcal{E},
\end{aligned}
\tag{E.30}
$$

where

$$
\mathcal{K} = \Phi\Theta(I-\Omega\Theta)^{-1}\delta\left[I-((1+\sigma)\Phi-\sigma I)\Theta(I-\Omega\Theta)^{-1}\delta\right]^{-1}(\sigma+\varphi),
$$

$$\mathcal{G} = \Phi \Bigg[\Theta(I - \Omega\Theta)^{-1}\delta[I - ((1+\sigma)\Phi - \sigma I)\Omega(I - \Omega\Theta)^{-1}\delta]^{-1}$$

$$[I - ((1-\sigma)I + \sigma\Phi)\Theta(I - \Omega\Theta)^{-1}] - \Theta(I - \Omega\Theta)^{-1} \Bigg],$$

and

$$\mathcal{H} = \Phi \Bigg[\Theta(I - \Omega\Theta)^{-1}\delta[I - ((1+\sigma)\Phi - \sigma I)\Theta(I - \Omega\Theta)^{-1}\delta]^{-1}$$

$$\left\{ ((1+\sigma)I - \sigma\Phi)\Theta(I - \Omega\Theta)^{-1}(1-\delta) \begin{pmatrix} 1-\mu \\ -(1-\mu^*) \end{pmatrix} + (1-\sigma) \begin{pmatrix} 1-\alpha \\ -(1-\alpha^*) \end{pmatrix} \right\}$$

$$+ \Theta(I - \Omega\Theta)^{-1}(\mathbf{1} - \delta) \cdot \begin{pmatrix} 1-\mu \\ -(1-\mu^*) \end{pmatrix} + \begin{pmatrix} 1-\alpha \\ -(1-\alpha^*) \end{pmatrix} \Bigg].$$

F The Dynamic Model of GVCs

Building on the static model we presented, here we introduce a two-country, multi-sector New Keynesian model with production networks.[19] The two countries, home (H) and foreign (F), are populated by a continuum of infinitely lived households with a fraction of (n) and (1-n) of the total world population, respectively. Foreign country variables will be denoted by an asterisk ($*$).

In each country, there is a continuum of firms indexed by $i \in [0, 1]$ and each firm belongs to a sector, $s \in 1, ..., S$. Firms produce differentiated products which can be sold domestically or exported for consumption and production. Our model thus incorporates GVCs through trade in intermediate inputs. In each sector, monopolistically competitive firms produce their output using labour and intermediate goods as inputs. In each period, producers choose how much intermediate input they want to buy from each sector and then they decide whether to buy home or foreign-produced intermediates. Similarly, we assume that aggregate consumption is a composite of sectoral consumption goods and each of these goods is a CES aggregate of home and foreign produced goods. Thus, there is trade in final goods as well. We assume that international asset markets are complete in the sense that consumers have access to state-contingent bonds that can be traded internationally.

[19] The modelling is quite standard. For instance Comin and Johnson (2020) presents a similar small open economy model with Rotemberg price adjustments instead of Calvo.

F.1 Households

Household preferences are identical across countries. Therefore we only explain the intertemporal decision of a representative household in the home country. Households receive utility from consumption, C, and disutility from supplying labor, L. The lifetime utility function of the representative household is given by:

$$U = \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \Xi \frac{L_t^{1+\varphi}}{1+\varphi} \right], \tag{F.1}$$

where $\mathbb{E}_t$ is the expectations operator conditional on time t information, $\beta \in (0, 1)$ is the discount factor, σ and φ denote the inverse of intertemporal elasticity of substitution and Frisch elasticity of labor supply, respectively. Finally, Ξ is a preference parameter that allows us to fix the hours worked in the steady state.

Households finance expenditure on consumption goods through labor income and profits from the ownership of firms. As in **?**, we assume that the international asset markets are complete in the sense that households can trade state-contingent securities that are denominated in the home currency to buy consumption goods. We assume that only bonds that are issued by home can be traded internationally. The period budget constraint of the home household is:

$$P_t C_t + \mathbb{E}_t Q_{t,t+1} B_{Ht+1} \leq B_{Ht} + W_t L_t + \Pi_t,$$

where P_t is the CPI, W_t is the nominal wage and Π_t is the nominal profits. B_{Ht+1} denotes the home households holding of nominal state-contingent internationally traded bonds which deliver one unit of home currency in period *t+1* if a particular state occurs. $Q_{t,t+1}$ is the price of such bond at time t.

First-order conditions to the home household's utility maximization problem yields:

$$\Xi C_t^{\sigma} L_t^{\varphi} = \frac{W_t}{P_t}, \tag{F.2}$$

and

$$Q_{t,t+1} = \beta \mathbb{E}_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \left(\frac{P_t}{P_{t+1}} \right) \right]. \tag{F.3}$$

Let the return on the nominal state contingent bond is equal to $(1 + i_t) = 1/Q_{t,t+1}$.

We then have the usual Euler equation:

$$\frac{1}{1+i_t} = \beta \mathbb{E}_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \left(\frac{P_t}{P_{t+1}} \right) \right]. \tag{F.4}$$

The foreign household's intertemporal decision yields similar expressions:

$$\Xi \, (C_t^*)^{\sigma} \, (L_t^*)^{\varphi} = \frac{W_t^*}{P_t^*}, \tag{F.5}$$

$$\frac{1}{1+i_t^*} = \beta \mathbb{E}_t \left[\left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\sigma} \left(\frac{P_t^*}{P_{t+1}^*} \right) \right], \tag{F.6}$$

and

$$Q_{t,t+1} = \beta \mathbb{E}_t \left[\left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\sigma} \left(\frac{S_t \, P_t^*}{S_{t+1} \, P_{t+1}^*} \right) \right], \tag{F.7}$$

where S_t is the nominal exchange rate defined as the home currency price of foreign currency.

Households' choice on internationally traded bonds, Equations (F.3) and (F.7), yield the international risk-sharing condition:

$$q_t = \Psi \left(\frac{C_t}{C_t^*} \right)^{\sigma}, \tag{F.8}$$

where $q_t = S_t \, P_t^* / P_t$ is the real exchange rate and $\Psi = Q_0 \left(\frac{C_0}{C_0^*} \right)^{\sigma}$ is a constant.

Each period households optimally allocate their total expenditure across sectoral goods. The final consumption basket, C_t, is a CES aggregate of finitely many sectoral goods ($s \in \{1, 2, \ldots, S\}$) in each country:

$$C_t = \left[\sum_{s=1}^{S} \eta_s^{\frac{1}{\theta_C}} \left(C_{st} \right)^{\frac{\theta_C - 1}{\theta_C}} \right]^{\frac{\theta_C}{\theta_C - 1}}, \tag{F.9}$$

where θ_C is elasticity of substitution between sectoral consumption goods and η_s is the share of sector s in total consumption with $\Sigma_s \eta_s = 1$.

Sectoral goods themselves are also CES aggregates of home, C_{Hst}, and foreign,

C_{Fst}, consumption goods such as:

$$C_{st} = \left[\alpha_s^{\frac{1}{\phi_{Cs}}} (C_{Hst})^{\frac{\phi_{Cs}-1}{\phi_{Cs}}} + (1-\alpha_s)^{\frac{1}{\phi_{Cs}}} (C_{Fst})^{\frac{\phi_{Cs}-1}{\phi_{Cs}}} \right]^{\frac{\phi_{Cs}}{\phi_{Cs}-1}}, \tag{F.10}$$

where α_s represents the share of home-produced goods in sectoral consumption and ϕ_{Cs} is the elasticity of substitution between home and foreign-produced consumption goods which is allowed to be different across sectors. As in the static set-up, the share of imported goods in each sector is a function of relative country size, $1-n$, and the degree of openness in final demand, v_{Cs}: $1-\alpha_s = (1-n)\, v_{Cs}$. When $\alpha_s > 0.5$, there is home bias in preferences in a given sector. Household expenditure minimization yields the following optimal demand for sectoral goods:

$$C_{st} = \eta_s \left(\frac{P_{st}}{P_t} \right)^{-\theta_C} C_t,$$

where the aggregate price index is $P_t = [\sum_{s=1}^{S} \eta_s P_{st}^{1-\theta_C}]^{\frac{1}{1-\theta_C}}$. Then, sectoral consumption is further allocated between home and foreign goods:

$$C_{Hst} = \alpha_s \left(\frac{P_{Hst}}{P_{st}} \right)^{-\phi_{Cs}} C_{st}, \quad C_{Fst} = (1-\alpha_s) \left(\frac{P_{Fst}}{P_{st}} \right)^{-\phi_{Cs}} C_{st},$$

where the sectoral price index is $P_{st} = [\alpha_s P_{Hst}^{1-\phi_{Cs}} + (1-\alpha_s) P_{Fst}^{1-\phi_{Cs}}]^{\frac{1}{1-\phi_{Cs}}}$. We assume that the law-of-one-price holds such that the price of foreign goods in the units of home currency is $P_{Fst} = S_t P_{Fst}^*$ and the price of home goods in the units of foreign currency is $P_{Hst}^* = P_{Hst}/S_t$. The situation of foreign households is analogous.

F.2 Firms

The supply side of the economy consists of perfectly competitive sectoral producers at the retail level and monopolistically competitive firms at the wholesale level.

Retail Producers

Infinitely many competitive firms aggregate firm level domestic varieties $Y_{Hst}(i)$ into sectoral goods Y_{Hst} using the following production function:

$$Y_{Hst} = \left[\int_0^1 Y_{Hst}^{\frac{\epsilon_s}{\epsilon_s-1}}(i) di \right]^{\frac{\epsilon_s-1}{\epsilon_s}},$$

where ϵ_s is the elasticity of substitution between varieties within a sector. The solution to this aggregation problem implies the following demand for varieties:

$$Y_{Hst}(i) = \left(\frac{P_{Hst}(i)}{P_{Hst}}\right)^{-\epsilon_s} Y_{Hst}.$$

Wholesale Producers

Now, we introduce the production process of individual varieties. Firms use labor and intermediate inputs to produce a unit of output. The production function is given by:

$$Y_{Hst}(i) = A_t A_{st} L_{st}(i)^{\delta_s} M_{st}(i)^{1-\delta_s}, \tag{F.11}$$

where L_{st} denotes firm i's labor demand and δ_s denotes the share of labor in production. Aggregate and sectoral productivity assumed to follow an AR(1) process and are represented by A_t and A_{st}, respectively

$$\log A_t = (1-\rho_A)\log \overline{A} + \rho_A \log A_{t-1} + \varepsilon_{At}, \tag{F.12}$$

$$\log A_{st} = (1-\rho_{As})\log \overline{A_s} + \rho_{As} \log A_{st-1} + \varepsilon_{Ast}, \tag{F.13}$$

where $\overline{A}$ and $\overline{A_s}$ represent the steady state values, $\rho_A \in (0,1)$ and $\rho_{A_s} \in (0,1)$ denote the persistence, and $\varepsilon_{A,t} \sim N(0, \sigma_A^2)$ and $\varepsilon_{A_s t} \sim N(0, \sigma_{A_s}^2)$ are iid innovations.

Each firm, i, uses intermediate good, $M_{st}(i)$, which is a CES aggregate of sectoral goods:

$$M_{st}(i) = \left[\sum_{s'=1}^{S} \omega_{ss'}^{\frac{1}{\theta_M}} \left(M_{ss't}(i)\right)^{\frac{\theta_M - 1}{\theta_M}}\right]^{\frac{\theta_M}{\theta_M - 1}}, \tag{F.14}$$

where $M_{ss't}$ is the intermediate good demand of sector s from sector s' at time t, and $\omega_{ss'}$ is the share of sector s' in total intermediate good expenditure of sector s with $\sum_{s'=1}^{S} \omega_{ss'} = 1$. The elasticity of substitution across sectoral intermediate goods is denoted by θ_M.

Firms' sectoral input demand is a CES aggregate of domestic and foreign intermediate goods as in the consumption case:

$$M_{ss't}(i) = \left[\mu_{ss'}^{\frac{1}{\phi_{Ms}}} \left(M_{Hss't}(i)\right)^{\frac{\phi_{Ms}-1}{\phi_{Ms}}} + (1-\mu_{ss'})^{\frac{1}{\phi_{Ms}}} \left(M_{Fss't}(i)\right)^{\frac{\phi_{Ms}-1}{\phi_{Ms}}}\right]^{\frac{\phi_{Ms}}{\phi_{Ms}-1}}, \tag{F.15}$$

where $M_{Hss't}(i)$ and $M_{Fss't}(i)$ denote domestic and foreign intermediate good demand of sector s from sector s' at time t, respectively. There exists sectoral home bias at the intermediate level denoted by $\mu_{ss'}$, and ϕ_{Ms} denotes the elasticity of substitution between home and foreign-produced intermediate goods which is allowed to be different across sectors. Similar to consumption preference structure, we assume that the share of imported intermediate goods is a function of relative country size, $(1-n)$, and the degree of openness in intermediate goods in a sector, $v_{Mss'}$: $1-\mu_{ss'} = (1-n)\, v_{Mss'}$.

Every period, firms choose the labor and intermediate inputs to minimize their costs. Optimal input demands then can be shown as:

$$L_{st} = \delta_s \left(\frac{MC_{st}}{W_t}\right) Y_{Hst}, \quad M_{st} = (1-\delta_s)\left(\frac{MC_{st}}{P^M_{st}}\right) Y_{Hst},$$

where MC_{st} is sectoral marginal cost (will be defined below) and P^M_{st} is the intermediate input price index for sector s. Firms also optimally choose sectoral intermediate goods as:

$$M_{ss't} = \omega_{ss'} \left(\frac{P^M_{ss't}}{P^M_{st}}\right)^{-\theta_M} M_{st},$$

where intermediate input price index is $P^M_{st} = \left[\sum_{s'=1}^{S} \omega_{ss'} \left(P^M_{ss't}\right)^{1-\theta_M}\right]^{\frac{1}{1-\theta_M}}$, and the demand for home and foreign sectoral inputs are given by:

$$M_{Hss't} = \mu_{ss'} \left(\frac{P_{Hs't}}{P^M_{ss't}}\right)^{-\phi_{Ms}} M_{ss't}\,, \quad M_{Fss't} = (1-\mu_{ss'}) \left(\frac{P_{Fs't}}{P^M_{ss't}}\right)^{-\phi_{Ms}} M_{ss't},$$

where sectoral intermediates price index is a weighted average of home and foreign sectoral output prices $P^M_{ss't} = \left[\mu_{ss'} P^{1-\phi_{Ms}}_{Hs't} + (1-\mu_{ss'}) P^{1-\phi_{Ms}}_{Fs't}\right]^{\frac{1}{1-\phi_{Ms}}}$.

By using firms' demand for factors of production, we can derive the sectoral nominal marginal cost:

$$MC_{st} = \frac{1}{A_t A_{st}} \left(\frac{W_t}{\delta_s}\right)^{\delta_s} \left(\frac{P^M_{st}}{1-\delta_s}\right)^{1-\delta_s}, \tag{F.16}$$

Note that sectoral linkages through input-output relationships at the intermediate goods level imply a sectoral marginal cost that depends on other sectors' output prices.

Firm's Pricing Decision

We assume that firms are subject to Calvo-type price rigidities such that a firm can update its price with a probability of 1-θ_s, where θ_s denotes the sector-specific price stickiness. Wholesale producer, i, that can re-set its price, maximizes the present discounted future value of profits

$$\mathbb{E}_t \sum_{k=0}^{\infty} \beta^k \frac{C_{t+k}^{-\sigma}}{C_t^{-\sigma}} \theta_s^k \left[P_{Hst}(i) Y_{Hst}(i) - MC_{st}(i) Y_{Hst}(i) \right],$$

subject to demand function

$$Y_{Hst}(i) \leq \left(\frac{P_{Hst}(i)}{P_{Hst}} \right)^{-\epsilon_s} Y_{Hst}.$$

The FOC to this problem implies the following nonlinear relationship between firms' reset prices and marginal cost

$$P_{Hst} = \frac{\epsilon_s}{\epsilon_s - 1} \frac{\mathbb{E}_t \sum_{k=0}^{\infty} \beta^k C_{t+k}^{-\sigma} \theta_s^k MC_{st+k} P_{Hst+k}^{\epsilon_s} Y_{Hst+k}}{E_t \sum_{k=0}^{\infty} \beta^k C_{t+k}^{-\sigma} \theta_s^k P_{Hst+k}^{\epsilon_s} Y_{Hst+k}},$$

where P_{Hst} is the reset price.

F.3 Market Clearing

Sectoral output can be used domestically for consumption and for further production as intermediate inputs or it can be exported, X_{st}. Exports can be consumed by foreign consumers or used by foreign firms as inputs. Thus, we can write the goods market clearing condition such that

$$Y_{Hst} = C_{Hst} + \sum_{s'=1}^{S} M_{Hs'st} + \underbrace{\frac{1-n}{n} \left(C_{Hst}^{*} + \sum_{s'=1}^{S} M_{Hs'st}^{*} \right)}_{X_{st}}.$$

We assume that labor is perfectly mobile across sectors but not across countries. Labor market clearing conditions then can be expressed as:

$$L_t = \sum_{s=1}^{S} L_{st}.$$

F.4 Monetary Policy

Monetary policy authority sets the nominal interest rate following a Taylor-type rule that targets the CPI inflation

$$\frac{i_t}{i} = \left(\frac{i_{t-1}}{i}\right)^{\Gamma_i} \left(\frac{\pi_t}{\pi}\right)^{\Gamma_\pi (1-\Gamma_i)} \exp(\epsilon_{mt}),$$

where $\epsilon_{mt} \sim N(0, \sigma_m^2)$ is the shock to the monetary policy.