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ABSTRACT

This paper starts by documenting a new fact that consumer price index (CPI) and producer price index (PPI) used to move in tandem within a given country around the world, but start to diverge after 2000. Understanding the source of divergence is important as it potentially affects optimal monetary policies. We propose an explanation via the lens of global value chains. With increased length of production chains, the baskets of CPI and PPI have become more different. We build a model with multi-stage production, and derive tractable analytical solutions to show this point. Moreover, in the model, as production becomes longer, both CPI and PPI become less responsive to a given shock to the first stage of production, and the reduction in responsiveness is greater for CPI. We show that the key predictions of the model are confirmed in the data. Furthermore, we compare model predictions at the country level using calibrations and empirical patterns, and find that the two line up well as well.

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1 Introduction

The fields of monetary economics and international trade are largely developed as two parallel universes, with minimum interactions between them. This paper explores implications of some insight and tools from the international trade field for variables that are central to monetary economics.

The increased integration of the world economy of the last several decades has brought disintegration of production in two senses: Production has become more segmented through outsourcing - parts and components that used to be produced within a firm, or service functions that used to be performed within a firm, are now increasingly likely to be purchased from outside the company - and offshoring - parts and components that used to be produced within a country are now increasingly purchased from abroad. Outsourcing and offshoring are not mutually exclusive - some of the outsourcing can take place across national borders. These phenomena have received ample attention in international trade and have been given many different labels, including "slicing the value chains" (e.g., Krugman, 1996), "delocalization" (e.g., Leamer, 1996), "disintegration of production" (e.g., Feenstra, 1999), "intra-mediate trade" (e.g., Antweiler and Trefler, 2002), and "lengthening of production" (e.g., Antràs et al., 2012; Wang et al., 2017). Feenstra (1999) provides a succinct survey of the earlier literature, whereas Antràs' book (2016) provides the latest synthesis and insight on the subject. One manifestation of this process is the rise of intermediate goods as a share of international trade (e.g., Johnson and Noguera, 2016), especially since 2001. This paper explores implications for inflation patterns - which is of intrinsic interest to monetary economics - of these phenomena, especially an acceleration of such process after 2001.

Inflation is a key variable that enters almost any central bank's objective function or policy reaction function. The Consumer Price Index (CPI) and Producer Price Index (PPI) are two gauges of inflation: the former measures changes in the prices of goods and services that households buy, while the latter measures changes in the prices of the goods (and some intermediate services) made by domestic producers.[1]

Central banks, in practice, typically target only CPI inflation, while the existing literature has studied whether CPI or PPI is more appropriate for monetary policy goal (e.g., De Paoli, 2009; De Gregorio, 2012). The literature suggests that, when the two diverge, both CPI and PPI should be taken into account for an optimal monetary policy (e.g., Huang and Liu, 2005; Strum, 2009). The intuition is that, in a New Keynesian model, a PPI inflation causes distortions in the allocation of productive resources, including among domestic producers of intermediate goods. Since all firms are owned by the households, the distortions associated with a PPI inflation reduce household welfare too.

We will show evidence that the practice of targeting only CPI inflation was nearly harmless before 2001, as CPI and PPI tended to move together anyway. This might be a key

[1] Most service items are typically excluded from the PPI in many countries.

reason for why central banks do not typically look beyond CPI inflation.

However, we will also show evidence of a divergence between the two indices since the beginning of this century. In many countries including the United States, China, Republic of Korea, India, Singapore, Thailand, Philippines and Malaysia, the two inflation indicators even went in opposite directions in the recent past: While the CPI changes were moderately positive, the PPI changes were negative. As a result, those monetary policies that pay attention only to CPI inflation might be sub-optimal. As important, as the intermediate goods become more important relative to labor input in processing final goods, the weights on PPI relative to the weights on CPI should be larger.

Whether central banks need to alter their practices or not depends on whether the divergence between CPI and PPI is structural or temporary. For this reason, it is important to understand why PPI and CPI have diverged in recent years. Yet, we are not aware of either theoretical or empirical papers that study the causes of the divergence. The objective of this paper is to study the role of supply chains in the divergence between CPI and PPI. More precisely, we study how a lengthening of global value chains (due to offshoring and outsourcing) affects the divergence of CPI and PPI. This is not a monetary economics paper; we take as given that a divergence in PPI and CPI is important for monetary policies. This is not a typical international trade paper either as PPI and CPI are not typical variables in a trade paper. Instead, it aims to use analytical tools about global value chains to explore novel insight for questions that are important for monetary economics.

In cross-border trade, the share of intermediate goods has increased sharply (e.g., Hummels, Ishii, and Yi, 2001; Johnson and Nuguero, 2016; Koopman, Wang, and Wei, 2014). With increasing digitalization and lower communication cost, a technical advancement that accelerated since 2001, production process can be and has been broken into an increasing number of segments (e.g., Fort, 2016). The average production length - measured by the average number of times that value added is counted in gross output - has indeed increased over the period 1995-2011, and the pace of increase accelerated after 2001 (e.g., Wang et al., 2017).

Before we proceed to the key idea in the paper, it is useful to clarify the differences between CPI and PPI, which lies chiefly in the coverage of goods and services. First, the CPI covers the set of goods and services purchased for consumption purposes for an average consumer or household. Second, the PPI measures the average of prices of all outputs sold by domestic producers. This means that, on the one hand, domestically produced intermediate goods are in the PPI basket but not in the CPI basket. On the other hand, imported final goods are in the CPI basket but not in the PPI basket. In addition, following the practice by most OECD countries, services, including residential rental, transport and telecommunication, health, and education, are excluded from the PPI index but are incorporated in the CPI index.

The key idea of this paper is that, as the production process becomes longer (or more globally fragmented), there is an increasing divergence in the composition of the baskets for CPI and PPI, which generates a reduction in the correlation between CPI and PPI. To clarify, the paper does not investigate why the production process has become longer. Instead, we study its implications for movements of CPI and PPI across countries and periods.

We build a multi-stage multi-country production model with Eaton-Kortum (2002) features in each stage of production, and explore how an increase in the number of production stages affects the relationship between CPI and PPI inflations. Specifically, we construct the model with two sectors, i.e., manufacturing sector and service sector, in which the production in manufacturing requires multiple stages for producing final goods while there is only one stage of production in service sector. We show that, in response to a productivity shock to early stages of manufacturing production (e.g., a shock to the global commodity price), the correlation between CPI and PPI declines as the number of production stages increases. More concretely, while both CPI and PPI inflation respond less to a given shock, the decline in the responsiveness of CPI inflation is faster.

Taking these predictions to the data, we will investigate how CPI and PPI react to a shock to international industrial input prices, which is a proxy for a productivity shock to the first stage manufacturing production. The literature on global value chains measures the production length by the average number of stages the value added in primary factors have to go through before being incorporated in the gross value of final goods and services. According to Wang et al. (2017), the length of the world production was relatively stable before 2001 (or exhibiting only a mild increase), but there appears to be an increase in the production length after 2001. We separate the sample into two sub-periods accordingly, i.e., before and after 2001, and study whether and how the impulse responses of PPI and CPI to a shock to the industrial input prices have changed in the two sub-periods. Consistent with the model, we find that both CPI inflation and PPI inflation have become less responsive to a 1% change in industrial input prices after 2001, and the decline in the responsiveness in percentage term is significantly greater for CPI than for PPI. As a robustness check, we also take the primary commodity price shocks as a proxy for productivity shocks to early stages production, and find similar patterns.

In the empirical section, we also compare our story with two other *ex ante* plausible stories: (a) an increase in the share of services in the consumption basket over time could have caused a decline in the correlation between the two inflation measures, and (b) greater competition exerted by increased international trade can reduce markups that manufacturing firms can charge, reducing the prices of the goods more than those of the service items, and potentially capable of producing a decline in the correlation between the two inflation measures. It is useful to note that the three hypotheses are not mutually exclusive. Nonetheless, the evidence in later sections suggests that the value chain hypothesis is a quantitatively important part of the overall story. In comparison, the other two explanations appear to be of limited significance.

If we were to restrict our ambition to explaining the average behavior of PPI and CPI, we do not need to consider the international aspect of the story. A closed-economy version of the story could deliver the results. However, the way that a lengthening supply chain manifests itself in the real world is that an increasing share of intermediate goods is produced by foreign countries and traded internationally.[2] In other words, an increasing internationalization of production appears to be a feature of an expanding supply chain. Since different countries have different comparative advantage (e.g., due to different trade costs and different productivity levels), the responses of CPI and PPI to a common global technology shock can vary by country. Our multi-stage and multi-country model also makes country specific predictions on these responses.

As a more ambitious exercise, for all countries covered in the World Input-Output Database (WIOD), we calibrate the theoretical responses of PPI at the country level to a first-stage productivity shock in the manufacturing sector. We take bilateral trade shares implied by WIOD data in 1998 and 2005 as the matching targets for the calibration. Thus, conditional on the information in WIOD, the model generates a list of country rankings in terms of their relative magnitude of PPI responses to a shock to the industrial input prices. Separately, we also perform country-by-country empirical estimation of the responses of PPI to changes in the global industrial input prices. This generates a second country ranking of the relative size of the PPI responses to a common shock to the global industrial input prices. Because the latter empirical estimation is purely "data driven," and does not use information from WIOD and does not rely on the theoretical model, it provides another check on whether the theoretical model is sensible. We find that we can easily reject the null that the two rankings of the relative PPI responses are uncorrelated (in favor of the alternative that they are positively correlated).

Our paper contributes to the literature in three aspects. First, it provides new insights on the choice of inflation targets for optimal monetary policy (e.g., the survey by Bernanke et al., 1999; the survey by Woodford, 2003; Huang and Liu, 2005; Edwards, 2006; De Paoli, 2009). Huang and Liu (2005) recognize the distinction between CPI and PPI, and show that both CPI and PPI should be targeted in an optimal monetary policy rule. To the best of our knowledge, we are the first in the literature to document that the divergence in the movement between CPI and PPI has become much stronger in recent years. We also suggest that the divergence between CPI and PPI depends on the development of global value chains. In other words, optimal monetary policy taking both PPI and CPI into account should incorporate the structure of production chains and country-specific trade

[2] Figure 10 in Appendix *A* presents evidence of an upward trend in the share of internationally traded (i.e., imported) intermediate goods in total intermediate goods for major countries.

characteristics.

Second, our paper contributes to a growing literature on global value chains. While the existing literature focuses on measurement or welfare implications of GVCs (e.g., Hummels et al., 2001; Yi, 2003; Johnson and Noguera, 2009; Yi, 2010; Ramondo and Rodriguez-Clare, 2013; Koopman, Wang, and Wei, 2014; Timmer et al., 2014), this paper studies how GVCs affect CPI and PPI indices, and suggests concrete relevance of GVCs for monetary economics.

The paper also connects with the literature on vertical integration in an international context (e.g., Antràs and Chor, 2013; Costinot, Wang, and Vogel, 2013; Johnson and Moxnes, 2013; Alfaro et al., 2015; Antràs and De Gortari, 2017). Johnson and Moxnes (2013) build a two-stage Eaton-Kortum-like model with a "snake" production structure to study how comparative advantage and trade costs shape production fragmentation, while Costinot, Wang, and Vogel (2013) propose a model of vertical specialization by assuming countries with different probability of making mistakes in processing. Antràs and Chor (2013) build a vertical-line production model with a focus on the tradeoff between outsourcing or integration at each stage of production. A key insight is that outsourcing provides the supplier with better incentives to invest, but integration gives the firm a better bargaining position due to residual control rights. One innovation of our paper is a multi-stage model with Eaton-Kortum features in every stage of production, and nonetheless yields a closed-form theoretical solution.

Antràs and De Gortari (2017) develop a multi-stage Eaton-Kortum-like model with a tractable solution. They focus on trade questions - the specialization of countries along GVCs, i.e., where production at each stage is located. In contrast, our paper studies how increasing fragmentation of production affects macroeconomic variables, namely, CPI and PPI inflation. In terms of modeling technique, we propose a new way to derive analytical results of a multi-stage GVC model. While Antràs and De Gortari (2017) assume incomplete information in production process and firms make decisions by looking forward, we assume complete information in decision making process and make fewer restrictions on the structure of country-stage-specific productivity. In addition, while Antràs and De Gortari (2017) feature a "snake" structure of manufacturing production, we feature a combination of "snake" and "spider" structures. These represent two alternative ways to obtain trackable analytical solutions to multi-country and multi-stage production models.

Third, it has been recognized that international trade can generate spillovers among countries and affect international transmissions of business cycles (e.g., Ambler, Cardia, and Zimmermann, 2002; Kose, Prasad, and Terrones, 2003; Boivin and Giannoni, 2008; Monacelli and Sala, 2009; Mumtaz and Surico, 2012; Jin and Li, 2012; Auer, Levchenko, and Sauré, 2016). In our model, GVCs and trade generate supply-side spillovers across countries. The paper is also the first that explicitly demonstrates how macro price variables, i.e., CPI and PPI, are affected by global value chains.

The rest of the paper proceeds as follows: Section 2 presents more statistics on a structural break in the relationship between CPI and PPI since 2001. Section 3 introduces the settings of the model; Section 4 solves the general equilibrium and formally defines CPI and PPI indices; Section 4.4 discusses the response of CPI and PPI inflation to productivity shocks and trade shocks; Section 5 further derives an explicit solution to the responses of CPI and PPI inflation to different type of shocks by assuming homogeneous countries; Section 6 reports the major empirical results for testing the model prediction; Section 7 shows the calibration results of the model by using World Input-Output Data; and Section 8 concludes the paper.

2 The divergence between CPI and PPI in the new century

We now present systematic evidence on a decline in the correlation between CPI and PPI after 2001. Figure 1 presents a time series of correlations between CPI and PPI across countries with available data from 1970-2015. Each blue point in the figure is the cross-sectional correlation of CPI and PPI inflation in a given year across all countries with available data. The top panel presents the correlation of the annual percentage changes of the two variables during the period; the middle panel presents the correlation of the two in terms of changes over 5-years; the bottom panel gives the correlation in terms of changes over 10-years. We can see clearly that the two price indices move together until 2000, and then show divergence afterwards.

Because the country coverage tends to increase over time, it may be useful to check if the pattern is driven by newly added countries. While CPI is available for most countries throughout the sample, progressively more countries over time collect and publish PPI data. One might wonder if the pattern of a decline in the correlation between the two inflation measures is due to a change in the country coverage. To alleviate this concern, we also compute correlations - represented by the red circles in the graph - for a (maximum) common set of countries since 1995. The basic pattern holds for the common set of countries as well, namely, the correlations between the two inflation measures were very high before 2000 and dropped in the 21st century.

Note that the great moderation of inflation for advanced countries started in early 1990s. Most developing countries that had high or hyperinflation in the 1970s or 1980s have gotten rid of very high inflation by 1990s. Yet, no significant decline in the correlation between CPI and PPI can be detected in the 1990s in these graphs. Nonetheless, in formal tests of the key hypotheses in the subsequent empirical section, we will include the initial level of inflation as a control variable.

We now switch to two cross sections of time series correlations. The data for a given country is divided into three sub-periods, 1996-2001, 2002-2007, and 2008-2013, for high-income and developing countries. For each country in each period, we compute a correlation between the two time series for CPI and PPI. Figure 2 and Figure 3 present the cross-country distributions of the country-specific time-series correlation between CPI and PPI inflation for the three periods, for each of the two country groupings, respectively. For comparability, we use the common set of countries for all three time periods. Compared with the period of 1996-2001, we see a decline in the country-specific time-series correlations for both high-income countries and developing countries during 2002-2007, although the correlation bounced back after the onset of the global financial crisis during 2008-2013.[3]

Focusing on the periods before the crisis, Figure 4 shows the cumulative distribution of time-series correlations across countries. It is obvious that the times-series correlations in the post-2001 period are stochastically dominated by those in the pre-2001 period. Indeed, a Komogolov-Smirnov test rejects the null of no difference between the two cumulative distributions at the 10% level, in favor of the alternative that the pre-2001 distribution curve stochastically dominates the post-2002 curve. A more direct Dunn's test reveals that the pre-2001 distribution curve stochastically dominates the post-2002 curve at the 1% level.[4] In other words, for a given country, the correlation between the two inflation measures is greater in the pre-2001 period than that in more recent years. A similar pattern is found for each of the sub-country groups, i.e., high-income countries and developing countries.

3 The model setting

Consider a model with N countries, denoted by $n = 1, 2, \cdots, N$, and two sectors, manufacturing sector denoted by m and service sector denoted by s, respectively. Within a sector, there is a unit continuum of goods, $u \in [0, 1]$. The manufacturing sector features a multi-stage production, and the output at each stage can be traded internationally. The service sector features a single-stage production, and the output is not traded internationally. Figure 5 illustrates the production processes of the manufacturing and service sectors for a country.

We assume that the market is perfectly competitive, all production processes feature constant returns to scale, and the productivity of production follows a Fréchet distribution

[3] One possible explanation for a temporary increase in the correlation during 2008-2013 is the Great Recession. That is, the financial crisis dominates the movements of price indices and leads them to move in tandem. Also, as shown in Kalemli-Özcan et al. (2014), the length of production chains shortens in periods of financial distress. Along the idea in this paper, a temporarily shorter production chain could lead to a temporarily higher correlation between CPI and PPI inflation during financial crises. The temporary rebound in the correlation in the immediate aftermath of the global financial crisis in fact is consistent with the hypothesis in this paper.

[4] The test results on stochastic dominance are robust to using different time windows (of 5-years, 6-years, or 7-years) to calculate country-specific time-series correlations.

across countries, sectors and stages.

3.1 The manufacturing sector

The manufacturing production requires G stages, and each stage follows a standard Eaton-Kortum framework.

In the first stage, the production function for good u in country n is given by

$$q_1^n(u) = Z_1^n(u) l_1^n(u)$$

where $Z_1^n(u)$ is the good-specific productivity in stage 1 of manufacturing sector in country n and $l_1^n(u)$ is the quantity of labor employed in production.

In each subsequent stage, production uses a combination of labor and a composite intermediate input. The production at stage g (for $g = 2, \ldots, G$) can be thought of as a two-step process. In the first step, a firm purchases differentiated goods produced in the previous stage, i.e., stage $g-1$, from all countries and forms a composite intermediate good. Specifically, the intermediate good to be used by country n in production stage g, $\bar{q}_g^n$, is a composite of all stage $g-1$ goods from all countries in the world:

$$\bar{q}_g^n = exp(\int_0^1 ln(\tilde{q}_{g-1}^n(u))du)$$

where $\tilde{q}_{g-1}^n(u)$ is the amount of country n's purchase of stage $g-1$ output for good u. In the second step, the firm combines the composite intermediate good with labor input to produce an output.

The production function for good u in stage g is given by

$$q_g^n(u) = \Theta \cdot Z_g^n(u) \bar{q}_g^n(u)^{\theta} l_g^n(u)^{1-\theta}$$

where $\Theta = [(1-\theta)^{1-\theta}\theta^{\theta}]^{-1}$ is a constant for normalization. Since the production of any good in stage g needs a bundle of output from the previous stage as a collective input, it captures a characteristic of an inter-country input-output table in which the output from all countries might be used as inputs into the production.

In the language of Baldwin and Venables (2013), the entire manufacturing production process follows a combination of a snake and a spider patterns. At a given stage, outputs from the previous stage from all over the world are purchased to form a composite intermediate input, resembling a spider pattern. Going from one stage of production to the next, the process resembles a snake pattern. [5]

Firms in each stage of manufacturing production could purchase inputs from any country,

[5] In comparison, the production process assumed in Antràs and De Gortari (2017) resembles a pure snake pattern.

but subject to a bilateral iceberg trade cost τ^{in} when the inputs are shipped from country i to country n.

The productivity in manufacturing stage g of country n, i.e., $Z_g^n(u)$, is independently drawn across countries, stages, and goods from a Fréchet distribution. In other words, the productivity $Z_g^n(u)$ follows

$$\begin{aligned} Pr(Z_g^n(u) \leq z) &= F_g^n(z) \\ &= e^{-T_g^n z^{-\kappa}} \end{aligned}$$

where T_g^n is the location parameter, κ is the shape parameter, and $g = 1, \ldots, G$.

3.2 The service sector

The service sector features a single stage of production for which labor is the only input. The production function for service output u in country n is given by

$$s^n(u) = Z_s^n(u) l_s^n(u)$$

Similar to the manufacturing sector, the good-specific productivity in the service sector of country n, i.e., $Z_s^n(u)$, is independently drawn across varieties and countries from a Fréchet distribution. In other words, the productivity $Z_s^n(u)$ follows

$$\begin{aligned} Pr(Z_s^n(u) \leq z) &= F_s^n(z) \\ &= e^{-T_s^n z^{-\kappa}} \end{aligned}$$

where T_s^n is the location parameter and κ is the shape parameter. [6]

3.3 Households

Households purchase the final-stage manufacturing products from both domestic and foreign firms, and services from domestic service producers. They first aggregate the purchased manufacturing goods and service items to form a manufacturing composite good and a service composite good, denoted as Q^n and S^n, respectively, by a constant elasticity of substitution (CES) transformation. That is,

$$Q^n = exp(\int_0^1 log(\tilde{q}_G^n(u))du)$$

$$S^n = exp(\int_0^1 log(s^n(u))du)$$

[6] For simplicity, we assume a common shape parameter for productivity distributions across countries, sectors and stages.

where $\tilde{q}_G^n(u)$ is the quantity of manufacturing good u purchased by households in country n and $s^n(u)$ is the quantity of service good u purchased by domestic households.

The composite goods are then combined by a Cobb-Douglas aggregation to form a final consumption basket, i.e.,

$$F^n = A(Q^n)^\alpha (S^n)^{1-\alpha}$$

where $A = [(1-\alpha)^{1-\alpha}\alpha^\alpha]^{-1}$ is a constant for normalization.[7] Households maximize the value of their consumption basket.

The aggregation process described above is equivalent to a two-tier utility function by a representative consumer (e.g., Costinot, Donaldson, and Komunjer, 2012). The upper-tier is Cobb-Douglas aggregation over two categories of the goods, while the lower-tier features constant elasticity of substitution among differentiated goods in each sector.

We assume that the total labor supply in each country is fixed, denoted by L^n, and labor is fully mobile between two sectors within a country but not across countries. Thus, there is a wage assignment for each country. We assume a balanced trade, which implies $w^n L^n = P_F^n F^n$.

4 General equilibrium

4.1 The CPI definition

CPI is defined as the weighted average of the prices faced by households, including the prices of final goods from both manufacturing sector and service sector. Given the wage assignment $\{w^1, \ldots, w^N\}$ in all the countries, first consider the price assignment of the manufacturing sector. Since all the goods are symmetric, we ignore the index u in productivity Z_g^n. The good-specific productivity in each stage and each country is drawn from a Fréchet distribution, i.e.,

$$Pr(Z_g^n \leq z) = F_g^n(z) = e^{-T_g^n z^{-\kappa}}$$

In the first stage of production, for a specific country n and good u, let $p_1^{in}(u) = \frac{w^i \tau^{in}}{Z_1^i}$ be the unit cost at which country i sells good u to country n in stage 1. Let $G_1^{in}(p) = Pr(p_1^{in}(u) \leq p)$. Then, we get

$$G_1^{in}(p) = Pr(Z_1^i \geq \frac{w^i \tau^{in}}{p}) = 1 - F_1^i(\frac{w^i \tau^{in}}{p})$$

Let $\tilde{p}_1^n(u) = min\{p_1^{1n}(u), \ldots, p_1^{Nn}(u)\}$ and $G_1^n(p) = Pr(\tilde{p}_1^n(u) \leq p)$ be the purchasing price distribution of good u produced in stage 1, which are taken as inputs for stage 2 in

[7] The aggregation process is assumed to be the same, i.e., identical α, for all countries.

country n. Then, we have

$$G_1^n(p) = Pr(\tilde{p}_1^n(u) \leq p) = 1 - exp[-\Phi_1^n p^\kappa]$$

where $\Phi_1^n = \sum_{i=1}^N T_1^i (w^i \tau^{in})^{-\kappa}$. Details about this result can be found in Appendix B.

Each subsequent stage of production consists of two steps, i.e., aggregation and production. In stage 2, for any country n, the goods purchased from the previous stage are first aggregated to form a composite intermediate good, i.e.,

$$\bar{q}_2^n = exp(\int_0^1 log(\tilde{q}_1^n(u))du)$$

$$\bar{p}_2^n = exp(\int_0^1 log(\tilde{p}_1^n(u))du)$$

Following the standard results of the Eaton-Kortum model, we have

$$\bar{p}_2^n = (\Phi_1^n)^{-\frac{1}{\kappa}}$$

which is a constant.

In the second step of stage 2, firms use the intermediate composite goods for production. Similar to the first stage, the unit cost of production in country i serving to country n is $p_2^{in}(u) = \tau^{in} \frac{(w^i)^{1-\theta}(\bar{p}_2^i)^\theta}{Z_2^i}$, and let $G_2^{in}(p) = Pr(p_2^{in}(u) \leq p)$. Then, we obtain

$$G_2^{in}(p) = Pr(Z \geq \tau^{in} \frac{(w^i)^{1-\theta}(\bar{p}_2^i)^\theta}{p}) = 1 - F_2^i(\tau^{in} \frac{(w^i)^{1-\theta}(\bar{p}_2^i)^\theta}{p})$$

Also, let $\tilde{p}_2^n(u) = min\{p_2^{1n}(u), \ldots, p_2^{Nn}(u)\}$, and $G_2^n(p) = Pr(\tilde{p}_2^n(u) \leq p)$ be the purchasing price distribution of good u produced in stage 2, which is taken as an input for stage 3 in country n. Note that $\{\bar{p}_2^i\}_{i=1}^N$ are constants, and thus $\{p_2^{1n}(u), \ldots, p_2^{Nn}(u)\}$ are independent of each other. This is a key technical innovation that allows us to derive tractable solution to the multi-stage Eaton-Kortum model by avoiding a sum or a product of Fréchet random variables.

Then, we have

$$G_2^n(p) = Pr(\tilde{p}_2^n(Z) \leq p) = 1 - exp[-\Phi_2^n p^\kappa]$$

where

$$\Phi_2^n = \sum_{i=1}^N T_2^i [\tau^{in}(w^i)^{1-\theta}(\bar{p}_2^i)^\theta]^{-\kappa}$$

The proof for this result is the same as in the first stage, which is shown in Appendix B.

Similarly, for all the subsequent stages, i.e., $\forall g \in \{2, \ldots, G\}$, we have

$$\bar{p}_g^n = (\Phi_{g-1}^n)^{-\frac{1}{\kappa}}$$

and

$$\Phi_g^n = \sum_{i=1}^{N} T_g^i [\tau^{in} (w^i)^{1-\theta} (\bar{p}_g^i)^{\theta}]^{-\kappa}$$

with

$$\Phi_1^n = \sum_{i=1}^{N} T_1^i (w^i \tau^{in})^{-\kappa}$$

The price of the final manufacturing composite in country n is therefore given by

$$P^n(m) = exp(\int_0^1 log(\tilde{p}_G^n(u))du) = (\Phi_G^n)^{-\frac{1}{\kappa}}$$

We next consider the price assignment in the service sector. Since the outputs are non-tradable, the price of good u in the service sector of country n is then given by

$$p_s^n(u) = \frac{w^n}{Z_s^n}$$

with distribution $G^n(p) = Pr(p_s^n(u) \leq p)$. The price distribution, $G^n(p)$, satisfies

$$G^n(p) = Pr(\frac{w^n}{Z_s^n} \leq p) = 1 - F_s^n(\frac{w^n}{p})$$

By CES aggregation, the price of the final service composite in country n is then given by

$$\begin{aligned} P^n(s) &= exp(\int_0^1 log(p_s^n(u))du) \\ &= (T_s^n)^{-\frac{1}{\kappa}} w^n \end{aligned}$$

As a result, the price for the aggregated consumption basket in country n is

$$P_F^n = P^n(m)^{\alpha} P^n(s)^{1-\alpha}$$

Definition 1: given wage assignment $\{w^1, \ldots, w^N\}$, the CPI in any country n is given by

$$CPI^n = P^n(m)^{\alpha} P^n(s)^{1-\alpha}$$

where

$$P^n(m) = (\Phi_G^n)^{-\frac{1}{\kappa}}$$

and

$$P^n(s) = (T_s^n)^{-\frac{1}{\kappa}} w^n$$

Note that Φ_G^n is given by forward induction, i.e.,

$$\Phi_1^n = \sum_{i=1}^{N} T_1^i (w^i \tau^{in})^{-\kappa}$$

$$\Phi_g^n = \sum_{i=1}^{N} T_g^i [\tau^{in} (w^i)^{1-\theta} (\Phi_{g-1}^i)^{-\frac{\theta}{\kappa}}]^{-\kappa}, \forall g \in 2, \dots, G$$

From the definition, the CPI in country n can also be expressed as a function of the wage assignment, bilateral trade costs, and the parameters capturing productivity in each country.

4.2 PPI definition

The Producer Price Index (PPI) is defined as a weighted average of selling prices charged by domestic manufacturing firms. On the one hand, the PPI basket not only excludes imported final goods, but also excludes service output. On the other hand, it includes domestically produced intermediate goods.

For output good u produced in stage g, $g = 1, \dots, G$, country n buys the good from country i if the price charged by country i is the lowest, i.e., $i = argmin\{p_g^{1n}(u), \dots, p_g^{Nn}(u)\}$. Following standard results of an Eaton-Kortum model, for $g = 2, \dots, G$, the probability of this event is given by

$$\pi_g^{in} = \frac{T_g^i [\tau^{in} (w^i)^{1-\theta} (\bar{p}_g^i)^{\theta}]^{-\kappa}}{\Phi_g^n} = \frac{T_g^i [\tau^{in} (w^i)^{1-\theta} (\Phi_{g-1}^i)^{-\frac{\theta}{\kappa}}]^{-\kappa}}{\Phi_g^n}$$

and for the first stage of production,

$$\pi_1^{in} = \frac{T_1^i [\tau^{in} w^i]^{-\kappa}}{\Phi_1^n}$$

Assume country n's total expenditure on purchasing output produced in stage g is X_g^n, $g = 1, \dots, G$, and the total spending of country n on goods from country i is X_g^{in}. For any specific good u, the spending of country n on country i for purchasing good u is expected to be π_g^{in} multiplied by its total spending on goods u. Since all the goods are symmetric, for $g = 1, \dots, G$, we have

$$\frac{X_g^{in}}{X_g^n} = \pi_g^{in}$$

The total earnings of country i at the end of stage g, $g = 2, \ldots, G$, are then given by

$$E_g^i = \sum_{n=1}^{N} \frac{T_g^i[\tau^{in}(w^i)^{1-\theta}(\Phi_{g-1}^i)^{-\frac{\theta}{\kappa}}]^{-\kappa}}{\Phi_g^n} X_g^n$$

and for the first stage of production,

$$E_1^i = \sum_{n=1}^{N} \frac{T_1^i[\tau^{in}w^i]^{-\kappa}}{\Phi_1^n} X_1^n$$

Given the production function in stage g, $g = 2, \ldots, G$, $1-\theta$ fraction of its total earnings at this stage is paid to domestic households as labor income, and θ fraction of its total earnings is used to buy inputs, i.e., outputs from the previous stage. Therefore, for $g = 2, \ldots, G$, the relationship between total earnings and total expenditure in country n in each stage is given by

$$X_{g-1}^n = \theta E_g^n$$

Using $w^n L^n = P_F^n F^n$, i.e., the balanced trade assumption, the total expenditure for any country n on the outputs of manufacturing sector produced in the final stage G is given by

$$X_G^n = \alpha P_F^n F^n = \alpha w^n L^n$$

Given the final-stage total expenditure X_G^n in country n, its total earnings at the end of stage g are given by backward induction, i.e.,

$$E_g^n = \sum_{i=1}^{N} \frac{T_g^n[\tau^{ni}(w^n)^{1-\theta}(\Phi_{g-1}^n)^{-\frac{\theta}{\kappa}}]^{-\kappa}}{\Phi_g^i} X_g^i, g = 2, \ldots, G$$

$$X_{g-1}^n = \theta E_g^n, g = 2, \ldots, G$$

and for the first stage,

$$E_1^n = \sum_{i=1}^{N} \frac{T_1^n[\tau^{ni}w^n]^{-\kappa}}{\Phi_1^i} X_1^i$$

Note that all the intermediate goods are symmetric. The producer price index, PPI, is then defined as the geometric mean of the domestic producer selling prices in all stages weighted by sales. In other words, the PPI in country n is given by

$$PPI^n = [\frac{w^n}{(T_1^n)^{1/\kappa}}]^{\omega_1^n} \cdot \Pi_{g=2}^G [\frac{(w^n)^{1-\theta}(\Phi_{g-1}^n)^{-\frac{\theta}{\kappa}}}{(T_g^n)^{1/\kappa}}]^{\omega_g^n}$$

where w_g^n is the weight of sales on geometric mean of selling prices in each stage, i.e.,

$$\omega_g^n = \frac{E_g^n}{\sum_{g=1}^{G} E_g^n}, g = 1, \dots, G$$

Definition 2: given wage assignment $\{w^1, \dots, w^N\}$, the PPI in country n is given by

$$PPI^n = [\frac{w^n}{(T_1^n)^{1/\kappa}}]^{\omega_1^n} \cdot \Pi_{g=2}^{G} [\frac{(w^n)^{1-\theta} (\Phi_{g-1}^n)^{-\frac{\theta}{\kappa}}}{(T_g^n)^{1/\kappa}}]^{\omega_g^n}$$

where

$$\omega_g^n = \frac{E_g^n}{\sum_{g=1}^{G} E_g^n}, g = 1, \dots, G$$

Note that E_g^n is given by backward induction, i.e.,

$$X_G^n = \alpha w^n L^n, \forall n$$

$$E_g^n = \sum_{i=1}^{N} \frac{T_g^n [\tau^{ni} (w^n)^{1-\theta} (\Phi_{g-1}^n)^{-\frac{\theta}{\kappa}}]^{-\kappa}}{\Phi_g^i} X_g^i, g = 2, \dots, G$$

$$X_{g-1}^n = \theta E_g^n, g = 2, \dots, G$$

$$E_1^n = \sum_{i=1}^{N} \frac{T_1^n [\tau^{ni} w^n]^{-\kappa}}{\Phi_1^i} X_1^i$$

PPI, defined as the domestic producer prices weighted by sales, can be expressed as a function of wage assignment, labor supply, bilateral trade costs and the parameters capturing productivity in each country.

4.3 The market clearing condition

The labor demand in country n can be derived from the total earnings in each stage of the production. Note that, in any stage g of manufacturing production, $g = 2, \dots, G$, the earnings paid to domestic households in country n is given by

$$I_g^n = (1 - \theta) E_g^n$$

Since the only input in the first stage is labor, households' income in the first stage is given by

$$I_1^n = E_1^n$$

Therefore, the total income for the households in country n is given by

$$I^n = \sum_{g=1}^{G} I_g^n + (1-\alpha)w^n L^n$$

$$= (1-\theta)\sum_{g=2}^{G} E_g^n + E_1^n + (1-\alpha)w^n L^n$$

where $(1-\alpha)w^n L^n$ is the labor income from the service sector.

Households' total income in country n must equal to the total expenditure in country n, which requires

$$I^n = w^n L^n, \forall n$$

$$\Longleftrightarrow (1-\theta)\sum_{g=2}^{G} E_g^n + E_1^n = \alpha w^n L^n, \forall n$$

Since labor supply is fixed, wages will be adjusted to make sure labor market clearing. This provides a system of $N-1$ independent equations to solve the wage assignment $\{w^1, \ldots, w^N\}$ up to a choice of numeraire.

4.4 Comparative Statics

We are ready to work out how CPI and PPI inflation rates respond to productivity and trade cost shocks, respectively. With an eye for deriving theoretical predictions that can be tested in the data, we focus on a productivity shock to the first stage of the manufacturing process that is common to all countries. (We will later use changes in the index of global industrial input prices as a proxy for such a shock, and conduct corresponding empirical testings.) We use ϵ_m to denote such a shock, and the location parameter for the stage-one productivity after the shock, $lnT_1^{'n}$, can be written as the log of the pre-shock location parameter value plus the shock, i.e.,

$$lnT_1^{'n} = lnT_1^n + \epsilon_m, \forall n$$

We use ϵ_s^n to denote a shock to the service sector productivity, which is unique to country n, and ϵ_τ to denote a shock to the trade cost, which is common for all countries, respectively.

$$lnT_s^{'n} = lnT_s^n + \epsilon_s^n, \forall n$$

$$ln\tau'^{in} = ln\tau^{in} + \epsilon_\tau, \forall i, n$$

where $lnT_s^{'n}$ represents the location parameter for the service sector productivity after the shock, and $ln\tau'^{in}$ represents the trade cost after the shock. The three shocks are assumed to be independent.

We conjecture that the wage assignment of all countries, $\{w^1, \ldots, w^N\}$, does not change after the productivity shocks and trade cost shocks. This conjecture can be verified through the labor market clearing conditions after we obtain the price assignment and labor assignment. Given the expression of Φ_g^n, $g \in \{1, \ldots G\}$, after the shocks, it becomes

$$\Phi_g^{'n} = \Phi_g^n \cdot e^{\theta^{g-1}\epsilon_m} \cdot e^{-\kappa(1+\theta+\cdots+\theta^{g-1})\epsilon_\tau}, \forall n$$

By the expressions of X_g and E_g, $g \in \{1, \ldots G\}$, in the definition of PPI, with the assumption of wage assignment not changing, X_g and E_g under the productivity shocks become

$$X_g^{'n} = X_g^n, \forall n$$

$$E_g^{'n} = E_g^n, \forall n$$

which implies that the weights on the prices for defining PPI do not change under the shocks, i.e., $\omega_g^{'n} = \omega_g^n$ for $\forall n$ and $g \in \{1, \ldots G\}$.

Since the total earnings of each country in each stage of manufacturing production do not change under the shocks, i.e., $E_g^{'n} = E_g^n$, the labor market clearing conditions under the productivity shocks are obviously satisfied. Therefore, we have verified that the wage assignment of all the countries, $\{w^1, \ldots, w^N\}$, does not change under the productivity shocks and trade cost shocks. The intuition of this result comes from two aspects. First, with the Cobb-Douglas utility function, households always spend a fixed fraction of their income, i..e., $(1-\alpha)w^nL^n$, on purchasing the outputs of the service sector. Since firms in the service sector make no profits in competitive markets, they always require a fixed labor demand, i.e, $(1-\alpha)L^n$, regardless of their productivity. Second, a common productivity shock at the first stage of manufacturing production and a common shock to trade costs do not affect comparative advantage in any stage of manufacturing process across countries. This means that the manufacturing production assignment across countries does not change. As a result, neither labor assignment nor wage assignment changes across countries.

By the definitions of CPI and PPI, the post-shock CPI and PPI measures in country n are given, respectively, by

$$lnCPI^{'n} = lnCPI^n - \frac{1-\alpha}{\kappa}\epsilon_s^n - \frac{\alpha}{\kappa}\theta^{G-1}\epsilon_m + \alpha\frac{1-\theta^G}{1-\theta}\epsilon_\tau$$

$$lnPPI^{'n} = lnPPI^n - [\sum_{g=1}^{G}\frac{\omega_g^n}{\kappa}\theta^{g-1}]\epsilon_m + [\sum_{g=2}^{G}\omega_g^n\frac{\theta-\theta^g}{1-\theta}]\epsilon_\tau$$

The log-deviations of the two price indexes after the shocks in country n are thus given by

$$\widehat{lnCPI^n} = -\frac{1-\alpha}{\kappa}\epsilon_s^n - \frac{\alpha}{\kappa}\theta^{G-1}\epsilon_m + \alpha\frac{1-\theta^G}{1-\theta}\epsilon_\tau \tag{1}$$

$$\widehat{lnPPI^n} = -[\sum_{g=1}^{G}\frac{\omega_g^n}{\kappa}\theta^{g-1}]\epsilon_m + [\sum_{g=2}^{G}\omega_g^n\frac{\theta-\theta^g}{1-\theta}]\epsilon_\tau \tag{2}$$

Inspecting these expressions, it is clear that a service-sector productivity shock ϵ_s^n would affect CPI but not PPI. This is a consequence of the Cobb-Douglas preference, under which the consumption of the manufacturing and service items are fully separable.

Importantly, as the total number of manufacturing stages G increases, the effect of a common productivity shock, ϵ_m, on CPI inflation becomes smaller relative to that of a country-specific service-sector shock, ϵ_s^n.

Mathematically, the correlation between the log-deviations of CPI and PPI in country n after the productivity shocks is given by

$$corr(\widehat{lnCPI^n}, \widehat{lnPPI^n}) = [1 + (\frac{1-\alpha}{\alpha\theta^{G-1}})^2\frac{var(\epsilon_s^n)}{var(\epsilon_m)}]^{-\frac{1}{2}} \tag{3}$$

Holding constant the variance of the productivity shocks, since $\theta < 1$, it is clear that this correlation, i.e., $corr(\widehat{lnCPI^n}, \widehat{lnPPI^n})$, is strictly decreasing in G, the total number of manufacturing stages.

While our discussion focuses on a common shock to the first-stage manufacturing production, it is useful to note that the same results hold for a shock to any other stage of manufacturing production.

5 The case of symmetric countries

Additional analytical results can be obtained if we impose some symmetry assumptions. In particular, let us assume a unit continuum of countries $n \in [0,1]$, each with identical labor supply, identical productivity distribution in each stage of manufacturing production, identical productivity distribution in the service sector, i.e., $L^n = L^i$, $T_g^n = T_g^i = T_g$, $T_s^n = T_s^i = T_s$ for $\forall n \neq i$ and $\forall g \in \{1,\ldots,G\}$, and identical bilateral trade costs, i.e., $\tau^{in} = \tau$ for $\forall i, n$. Under these symmetry assumptions, the wages must be equal across all countries, i.e., $w^n = w$ for $\forall n$. In this case, international trade happens because the realizations of productivity are different across countries.

By the CPI definition, we have

$$\Phi_1 = \int_0^1 T_1(w\tau)^{-\kappa}dn$$

$$= T_1(w\tau)^{-\kappa}$$

Note that Φ_g^n is determined by forward induction in the case of a finite number of countries. That is,

$$\Phi_g^n = \sum_{i=1}^{N} T_g^i[\tau^{in}(w^i)^{1-\theta}(\Phi_{g-1}^i)^{-\frac{\theta}{\kappa}}]^{-\kappa}, \forall g \in 2, \ldots, G$$

Φ_g, $g = 2, \ldots, G$, under the continuous country assumption is then given by

$$\Phi_g = \int_0^1 T_g[\tau(w)^{1-\theta}(\Phi_{g-1})^{-\frac{\theta}{\kappa}}]^{-\kappa} dn, \forall g \in 2, \ldots, G$$

which implies

$$\Phi_g = [\Pi_{j=1}^g T_j^{\theta^{g-j}}][\tau^{-\kappa(\sum_{j=1}^g \theta^{j-1})}]w^{-\kappa}, \forall g = 2, \ldots, G$$

Denote $A_g = [\Pi_{j=1}^g T_j^{\theta^{g-j}}][\tau^{-\kappa(\sum_{j=1}^g \theta^{j-1})}]$, and then $\Phi_g = A_g w^{-\kappa}$. CPI is thus given by

$$CPI = P(m)^{\alpha}P(s)^{1-\alpha} = A_G^{-\frac{\alpha}{\kappa}} T_s^{-\frac{1-\alpha}{\kappa}} w \tag{4}$$

where $A_G = [\Pi_{j=1}^G T_j^{\theta^{G-j}}][\tau^{-\kappa(\sum_{j=1}^G \theta^{j-1})}]$.

We now turn to PPI. By the PPI definition, for $g = 1, \ldots, G$, we have

$$X_g = \theta^{G-g}\alpha wL,\ E_g = X_g = \theta^{G-g}\alpha wL$$

Then, the weights on prices in forming PPI in any stage g, $g = 1, \ldots, G$, is given by

$$\omega_g = \frac{\theta^{G-g}}{\sum_{j=1}^G \theta^{j-1}} = \frac{\theta^{G-g}}{1-\theta^G}(1-\theta)$$

PPI is thus given by

$$PPI = [\frac{w}{(T_1)^{1/\kappa}}]^{\omega_1} \cdot \Pi_{g=2}^G [\frac{(w)^{1-\theta}(\Phi_{g-1})^{-\frac{\theta}{\kappa}}}{(T_g)^{1/\kappa}}]^{\omega_g}$$

$$= [\Pi_{g=1}^G T_g^{-\frac{\omega_g}{\kappa}}][\Pi_{g=2}^G A_{g-1}^{-\frac{\theta}{\kappa}\cdot\omega_g}]w \tag{5}$$

From the expression of CPI and PPI, i.e., Equation 4 and 5, by taking natural log for both sides of the expressions, we have

$$lnCPI = -\frac{1-\alpha}{\kappa}lnT_s - \frac{\alpha}{\kappa}[\sum_{g=1}^G \theta^{G-g} \cdot lnT_g] + \alpha\frac{1-\theta^G}{1-\theta}ln\tau + lnw$$

and

$$lnPPI = -[\sum_{g=1}^{G} \frac{\omega_g}{\kappa} lnT_g] - \frac{\theta}{\kappa}[\sum_{g=2}^{G} \omega_g \cdot lnA_{g-1}] + lnw$$

Note that, by taking natural log on the expression of A_g, it gives

$$lnA_g = \sum_{j=1}^{g} \theta^{g-j} lnT_j - \kappa \frac{1-\theta^{g-1}}{1-\theta} ln\tau$$

Substituting ω_g and lnA_g into the expression of $lnPPI$, we then have

$$lnPPI = -[\sum_{g=1}^{G} \frac{\theta^{G-g}(1-\theta)(G-g+1)}{\kappa(1-\theta^G)} lnT_g] + \frac{\theta - G\theta^G + (G-1)\theta^{G+1}}{(1-\theta)(1-\theta^G)} ln\tau + lnw$$

With the expressions of $lnCPI$ and $lnPPI$, we proceed with Proposition 1. [8]

Proposition 1 *Given a unit continuum of symmetric countries $n \in [0,1]$, with identical bilateral trade costs, wages are identical across countries. The market equilibrium always exists, and the CPI and PPI indices are given, respectively, by*

$$lnCPI = -\frac{1-\alpha}{\kappa} lnT_s - [\sum_{g=1}^{G} \frac{\alpha}{\kappa} \theta^{G-g} \cdot lnT_g] + \frac{\alpha(1-\theta^G)}{1-\theta} ln\tau + lnw$$

$$lnPPI = -[\sum_{g=1}^{G} \frac{\theta^{G-g}(1-\theta)(G-g+1)}{\kappa(1-\theta^G)} lnT_g] + \frac{\theta - G\theta^G + (G-1)\theta^{G+1}}{(1-\theta)(1-\theta^G)} ln\tau + lnw$$

We can now derive explicit expressions about how CPI and PPI inflation respond to different types of shocks.

5.1 Productivity shock in the manufacturing sector

Consider a common global shock to the first stage productivity in the manufacturing production, lnT_1. By Proposition 1, the responses of CPI and PPI are given, respectively, by

$$\widehat{lnCPI} = -\frac{\alpha}{\kappa} \theta^{G-1} \widehat{lnT_1}$$

$$\widehat{lnPPI} = -\frac{G}{\kappa} \frac{(1-\theta)\theta^{G-1}}{1-\theta^G} \widehat{lnT_1}$$

[8] It can be easily verified that, in the current settings, an equilibrium always exists.

which yield

$$\frac{\widehat{lnPPI}}{\widehat{lnCPI}} = \frac{G(1-\theta)}{\alpha(1-\theta^G)}$$

It is obvious that the response of CPI inflation to the productivity shock, i.e., $|\widehat{lnCPI}/\widehat{lnT_1}| = \frac{\alpha}{\kappa}\theta^{G-1}$, is strictly decreasing with respect to the number of total stages, G. For the response of PPI inflation, given $\theta \in (0,1)$ and $G \geq 1$, it is also strictly decreasing with respect to the number of total stages. The proofs can be found in Appendix C. Furthermore, the right hand side of the expression of $\widehat{lnPPI}/\widehat{lnCPI}$ can be shown to be strictly increasing in the number of total stages, G. Details can be found in Appendix D. This implies Proposition 2.

Proposition 2 *As the number of manufacturing production stages increases, both CPI and PPI inflation become less responsive to a common global productivity shock in the first stage of manufacturing production, but the CPI inflation exhibits a greater decline in the responsiveness.*

5.2 A decline in the correlation between the two inflation measures

We consider a common global productivity shock in the first stage of manufacturing sector, i.e., lnT_1, together with a productivity shock in the service sector, i.e., lnT_s. By Proposition 1, the responses of CPI and PPI are given by

$$\widehat{lnCPI} = -\frac{\alpha}{\kappa}\theta^{G-1}\widehat{lnT_1} - \frac{1-\alpha}{\kappa}\widehat{lnT_s}$$

$$\widehat{lnPPI} = -\frac{G}{\kappa}\frac{(1-\theta)\theta^{G-1}}{1-\theta^G}\widehat{lnT_1}$$

Holding constant the variances of the $\widehat{lnT_1}$ shock and $\widehat{lnT_s}$ shock, as the number of manufacturing stages, G, increases, $-\frac{\alpha}{\kappa}\theta^{G-1}\widehat{lnT_1}$, becomes smaller relative to $-\frac{1-\alpha}{\kappa}\widehat{lnT_s}$. Since $\widehat{lnT_1}$ is the common component in the two inflation indexes, the correlation between $\widehat{lnCPI}$ and $\widehat{lnPPI}$ would become smaller too. This echoes the results derived under heterogeneous countries as showed in Equation 3. Formally, we have Proposition 3.

Proposition 3 *Holding constant the variances of the productivity shocks in the manufacturing and service sectors, as the number of manufacturing stages increases, the correlation between $\widehat{lnCPI}$ and $\widehat{lnPPI}$ decreases.*

We might contrast this proposition with what would happen under simultaneous global shocks to both service and manufacturing sectors. Where there is a common global shock in all sectors, CPI and PPI could become more, not less, correlated. An example of such a simultaneous shock might be the global financial crisis of 2008-2010, which likely had negatively affected all sectors at the same time.

5.3 Common shocks in trade costs

Consider a common shock to trade costs, i.e., $ln\tau$. By Proposition 1, the responses of CPI and PPI are given by

$$\widehat{lnCPI} = \frac{\alpha(1-\theta^G)}{1-\theta}\widehat{ln\tau}$$

$$\widehat{lnPPI} = \frac{\theta}{1-\theta}[1 - \frac{G\theta^{G-1}(1-\theta)}{1-\theta^G}]\widehat{ln\tau}$$

Since $\theta < 1$, it is obvious that CPI inflation would become more responsive to a shock to the trade costs shock as the number of manufacturing stages, G, increases. Similar to the proof in Appendix C, it can be shown that PPI inflation would also become more responsive. To see the intuition, it is important to recognize that trade costs exist in each stage of the manufacturing production. Therefore, as the number of manufacturing stages increase, the total impact of trade costs on both CPI and PPI becomes greater.

Note that a reduction in the trade costs does not by itself lead to a lower correlation between CPI and PPI inflation. To produce a lower correlation, it is necessary for the variance of the trade cost shocks to decline much more than the variance of the productivity shocks to the service sector. Otherwise, with an increase in the number of manufacturing production stages, the correlation could increase as the greater trade costs simultaneously raise both CPI and PPI more than proportionately.

6 Empirical tests

A rise in the length of production process from the pre-2001 period to the post-2002 period - as documented in Wang et al. (2017) - is in theory capable of generating a decline in the correlation between CPI and PPI inflation measures, the empirical pattern that motivates this paper. To solidify macroeconomic significance of this model that stresses an expanding production chain, we now check for empirical validity of other model-predicted consequences of a rise in the production length. In particular, as stated by Proposition 2 in Section 5, we will check if the responsiveness of both CPI and PPI to a common global productivity shock in the first-stage manufacturing production indeed becomes weaker after 2002,

Since the countries in the real world are not symmetric, the closed-form predictions in the model might be regarded as an approximation for predictions in an asymmetric world.[9]

[9] In the case of heterogeneous countries, from Equation 1, it is clear that, as the number of production stages increases, the response of CPI inflation to the first stage productivity shock becomes smaller, but it

Indeed, in Section 7.1, we use calibrations to show that similar predictions emerge from the model without the symmetric assumptions.

Since productivity shocks are not directly observed, we use observed changes in the global industrial input price index as a proxy for common global productivity shocks in the first-stage manufacturing production. Industrial inputs - metals and agricultural raw materials for manufacturing purposes - are disproportionally used in the very early stage of manufacturing production.[10] Thus, a change in the cost of industrial inputs can be viewed as a shock to the productivity of the first-stage manufacturing production.

It is useful and important to note that Proposition 2 should also hold for a productivity shock to any other fixed stage g of the manufacturing process (not just the first stage of production). As long as the change in industrial input prices can be regarded as a shock to early stages of production, we should expect to see similar patterns in the CPI and PPI responses.

As a robustness check, we will also use changes in the primary commodity price index as an alternative proxy. The primary commodity price index is constructed by merging the industrial input price index together with energy prices and prices for other non-fuel commodities (i.e., food and beverages).

We start with data in annual frequency that covers the period from 1980 to 2014. The data for CPI, PPI, and wage per hour are measured in local currency, and collected from national sources. Note that the Global Financial Crisis that started in 2008 might be regarded as a different and special shock. In order for the empirics not to be "contaminated" by the Global Financial Crisis, we have also conducted a robustness check in which the sample stops at 2007, and find the same results.

Figure 6 shows the number of countries for which both CPI and PPI data are available in each year. They range from 36 countries in 1980, 47 in 1990, 78 in 2000, and 86 in 2010. The industrial input price index, available from 1980 onwards, and the primary commodity price index, available from 1992 onwards, are both constructed and reported by the International Monetary Fund. Both are denominated in US dollars. In later regressions, they are converted into local currencies.

As documented earlier, there appears to be a structural break for the production length and in the relationship between CPI and PPI around 2001. We thus separate the sample into two sub-samples: 1980-2001 and the other with 2001-2014.

is not straightforward for the response of PPI inflation.

[10] More precisely, the industrial input price index is constructed by the prices in two categories: metals and agricultural raw materials (those for manufacturing purposes). Metals include Copper, Aluminum, Iron ore, Tin, Nickel, Zinc, Lead, and Uranium; agricultural raw materials include timber, softwood, cotton, wool, rubber, and hides. Details can be found in the IMF report, "Indices of primary commodity prices, 2007-2017 (by group, in terms of U.S.$)".

6.1 Empirical tests

We use industrial input price changes as a proxy for the common productivity shock to the first stage production in manufacturing sector. Our baseline specification is given by the following:

$$\Delta lnCPI_t^n = \beta_1 \cdot \Delta lnCPI_{t-1}^n + \beta_2 \cdot \Delta lnP_{Industrial,t}^n + X_t^n + \epsilon_{CPI,t}^n \tag{6}$$

$$\Delta lnPPI_t^n = \gamma_1 \cdot \Delta lnPPI_{t-1}^n + \gamma_2 \cdot \Delta lnP_{Industrial,t}^n + X_t^n + \epsilon_{PPI,t}^n \tag{7}$$

where $\Delta lnP_{Industrial,t}^n$ denotes the log-change in industrial input price in local currency, and X_t^n indicates other control variables including log-change of nominal wage per hour, year dummies denoting the Great Recession period, domestic price index level and country fixed effects. All the variables are denominated in nominal local currency term.

The baseline results of the specification are shown in Table 1. Columns 1 and 2 use the pre-2001 sample, while Columns 3 to 6 use the post-2001 sample. Dummies denoting the period of Global Financial Crisis are controlled in Columns 5 and 6. As we can see, the coefficient on changes in industrial input prices, i.e., $\Delta lnP_{Industrial,t}$, is significantly positive in all columns. This is not surprising.

To shed light on the validity of our model, we compare the evolutions in the responses of the two inflation measures to changes in industrial input prices in the pre-2001 and post-2001 sub-samples. We can see that both CPI inflation and PPI inflation become less responsive after 2001, and the response of CPI decreases even faster than that of PPI. These patterns are consistent with Proposition 2.

To formally test the last statement, we report the ratio of PPI inflation response divided by the CPI inflation response, i.e., $\frac{\partial \Delta lnPPI_t / \partial \Delta lnP_{Industrial,t}}{\partial \Delta lnCPI_t / \partial \Delta lnP_{Industrial,t}}$ in Table 1. It shows that the response of PPI inflation relative to the response of CPI inflation becomes larger after 2001, i.e., the ratio is 1.334 in the pre-2001 period and becomes 4.706 in the post-2001 period. By one-sided test, we can see that the response ratio between PPI and CPI inflation is significantly larger in the post-2001 period. In other words, given that both CPI and PPI inflation respond less to the industrial input price change, the response of CPI is decreasing faster than that of PPI.

To check whether the results are driven by the financial crisis, we have also controlled the year dummies denoting the Great Recession, i.e., the year of 2008 and 2009, in Table 1, and all the results are robust.

To be closer to the theoretical model, we have also controlled the country-specific labor cost, i.e., nominal wage per hour, as reported in Table 2. Since wage data are missing for half of the sample, and most countries reporting wage data are developed countries, we construct the variable, $WageDummy * \Delta lnwage_t$, in the regression to utilize the information in the full sample set. More specifically, it equals $\Delta lnwage_t$ if wage data are available; otherwise, it equals 0. As we can see in Table 2, consistent with the analysis for Table 1, all the coefficients before the log-change in industrial input price are positive and significant. Compared with the pre-2001 period, both CPI and PPI inflation in the post-2001 sample are less responsive to changes in the industrial input prices, and the decline in the responsiveness of CPI is greater.

To see if the inflation responsiveness could be affected by the level of inflation itself, we control for the one-year lag of the log price level, i.e., $lnCPI$ and $lnPPI$, in Table 3. The one-sided ratio test rejects the null of no difference in the change in sensitivity between CPI and PPI, in favor of the alternative that the decline in CPI's sensitivity is greater, with a p-value of 1.6% when the global financial crisis period is not controlled for, and with a p-value of 2.4% when the global financial crisis period is controlled for. In other words, our conclusion on the relative changes in the sensitivity of CPI and PPI to industrial input prices from the pre-2001 sample to the post-2002 sample is robust to controlling for the level of inflation.

Jasova et al. (2016) have documented that the pass-through of exchange rate to consumer prices has fallen in emerging markets since 2000. It may be useful to also separate exchange rate changes from changes in global industrial input prices in dollar terms. We do so in Table 4. As we can see, while the coefficients before the log-change of industrial input price become smaller compared with those in Table 1, 2 or 3, they are still significantly positive. Most importantly, we continue to find that both CPI and PPI respond less to the industrial input prices after 2001. Furthermore, with the p-value of a one-sided ratio test of 1.1% in Column 3 and 4, and 1.5% in Column 5 and 6, the decline in the CPI inflation's responsiveness is greater than that of PPI inflation. In addition, similar to Jasova et al. (2016), the coefficients for the exchange rate pass-through are also smaller after 2001.

With a lagged dependent variable on the right-hand side in Specification 6 and 7, the least-squares dummy variable (LSDV) estimator may not be consistent. To address this issue, we adopt a quasi-maximum likelihood (QML) estimator (Hsiao, Pesaran, and Tahmiscioglu, 2002) for dynamic panel data. As robustness checks, we also use the Arellano-Bond estimator (Arellano and Bond, 1991), and the LSDV estimator. As reported in Appendix E, these results are qualitatively the same as what is reported here.

6.2 Robustness checks

As a robustness check, we use the primary commodity price index constructed by the IMF as a proxy for a productivity shock in the first-stage manufacturing production. The index incorporates the industrial input price index with energy prices, i.e., crude oil, natural gas, and coal prices, and other non-fuel commodities prices, i.e., food and beverage prices.[11]

[11] More precisely, the food category within the primary commodity price index defined by IMF includes cereals, vegetable oils or protein meals, meat, seafood, sugar, bananas, and oranges, while the category of

More specifically, the weight of the primary commodity price index on industrial inputs price is 18.4%, and the weight on energy price is 63.1%, and the weight on other non-fuel commodities price (i.e., food and beverage) is 18.5%. In other words, energy price plays a relatively more important role in the change of the primary commodity price index.

On the one hand, since energy is used in all stages of production, an exogenous change in the energy price might be regarded as a shock to all stages of manufacturing production. On the other hand, crude oil, natural gas, and coal, can be inputs for manufacturing process, and especially are taken as initial inputs for producing chemical relevant products. Therefore, we might still view the change in energy price as a shock primarily to early stages of production. Nonetheless, since the commodity price shock also affects later stages of production, our model implies that both PPI and CPI would become more responsive to such a shock than to one in the first stage of manufacturing production only.

Using similar specifications as Specification 6 and 7, we have

$$\Delta lnCPI_t^n = \beta_1 \cdot \Delta CPI_{t-1}^n + \beta_2 \cdot \Delta lnP_{Commodity,t}^n + X_t^n + \epsilon_{CPI,t}^n$$

$$\Delta lnPPI_t^n = \gamma_1 \cdot \Delta lnPPI_{t-1}^n + \gamma_2 \cdot \Delta lnP_{Commodity,t}^n + X_t^n + \epsilon_{PPI,t}^n$$

where $\Delta lnP_{Commodity,t}^n$ denotes the log-change of primary commodity price in local currency, and X_t^n indicates other control variables including log-change of nominal wage per hour, year dummies denoting the Great Recession period, domestic price index level and country fixed effects. All the variables are denominated in nominal terms and local currency. The estimation is conducted with a quasi-maximum likelihood method.

Table 5 and 6 show the responses of both CPI and PPI inflation to commodity price changes. In both tables, the coefficients before the log-change in the primary commodity price index are significantly positive in all columns. More importantly, both CPI and PPI inflation respond less to changes in commodity prices after 2001, and the decline is greater for CPI.

Comparing Columns 3 to 6 in Table 1 and 5, the responsiveness of CPI and PPI to commodity prices is indeed greater than to industrial input prices. Similar patterns hold when comparing Columns 3 to 6 in Table 3 and 6. These patterns are also consistent with the model implications. Again, when we use the Arellano-Bond estimator or the LSDV estimator, the results are robust.

6.3 Comments on alternative explanations

Two other factors could explain a secular decline in the correlation between CPI and PPI as well. First, if the share of services in the consumption basket rises over time, it could drive an increasing wedge between the two inflation measures over time and therefore a decline

beverages includes coffee, cocoa beans, and tea.

in their correlation. Second, if globalization exerts more downward pressure on the prices of goods than on the prices of services, it could also lead to a reduction in the correlation between the two measures of inflation.

Note that the global value chain story and these two factors are not mutually exclusive. All three could take place in the data. Nonetheless, we explore the implications of these two alternatives and conclude that they do not play a big role in the documented decline in the CPI-PPI correlation.

Recall that the dramatic decline in the CPI-PPI correlation took place around 2001, with virtually no visible change in the correlation before. To be consistent with this pattern, both of the two alternative stories would require a discrete increase in the rising trend of the service expenditure share in the consumption basket around 2001. We check this prediction using data in WIOD. Figure 7 presents the results for the largest advanced and emerging market economies. As we can see, this prediction is not supported in the data. In fact, in China, Japan, United Kingdom, India, and the European Union as a whole, the change in the service share after 2001 appears to be below the pre-2001 trend. (The dashed lines in Figure 7 represent a country-specific trend constructed from the data from 1995 to 2001.) If we look at the median share of service expenditures in the consumption basket across all countries in the sample (the bottom-right graph), the post-2001 share also appears to be below the trend. Furthermore, if the rising share of services explanation does matter a lot for the CPI-PPI correlation, the rising trend of service share before 2001 as showed in Figure 7 is not consistent with the fact that, as illustrated in Figure 1, the correlation between CPI and PPI inflation is nearly constant before 2001.

Switching to data for OECD countries, the median share of services (excluding housing) in the CPI basket, reported in Figure 8, also shows that the post-2001 increase is below a simple linear trend. These patterns suggest that the two alternative stories unlikely have played a major role in explaining a dramatic decline in the correlation between CPI and PPI after 2001.

The two alternative stories also carry predictions for the sensitivity of the CPI and PPI indices to a change in the industrial input prices. In particular, if an increase in the service share in the consumption basket is the only change (with no increase in the stages of production), then the PPI responsiveness to a change in the industrial input prices should not change. This is not supported by the evidence in all the regression tables so far.

Under the globalization story (globalization reduces the markups on internationally trade goods more than those on service items), the PPI index should become more responsive to a given change in the global industrial input prices. This is also inconsistent with the results in all the regression tables so far.

7 Quantitative Analysis of the Model

We have used the model to derive qualitative predictions about the average behavior of PPI and CPI in the previous sections. In the previous section, we focus on the average behavior across all countries. We now attempt something more ambitious, which is to derive quantitative predictions that may vary by countries, and check them against the data. In particular, we (1) use the model and the data on international trade to back out productivity realizations at each stage of production in each country and trade costs for each country pair, under two assumed lengths of manufacturing production, (2) derive the responses of PPI to a shock to the productivity in the first-stage manufacturing production in each case, (3) empirically estimate country-specific responses of PPI to changes in the global industrial input prices, and (4) compare the empirical patterns in (3) with the model predictions in (2).

It is worth emphasizing that the test in (4) is demanding as (2) and (3) draw on two completely different datasets. While (2) uses the input-output relationship in WIOD and bilateral trade data, (3) uses nationally reported PPI data and the IMF-reported global industrial input price index. Our theory is the only one in the literature that explicitly tie these two together.

We have two objectives in mind for the exercise in this section. First, in the model calibrations, we do not have to maintain symmetric assumptions as in Section 5. We verify that Proposition 2 that has been derived under the symmetric assumptions also holds in calibrations without these assumptions. Second, while the previous empirical section investigates the average behavior of CPI and PPI across countries, this section attempts something more ambitious - checking whether the empirical data patterns at the level of individual countries are consistent with the model predictions that allow for country heterogeneity.

Note that we choose to focus on heterogeneity in PPI only in this exercise. The reason is that, for WIOD countries, the dispersion in the empirically estimated PPI elasticity to the industrial input price index is substantially larger than that of CPI (i.e., 0.074 versus 0.038). (An F-test easily rejects the null that the two dispersions are the same in favor of the alternative that the PPI elasticities are more dispersed.)

It is useful to note that, to study the average behavior of PPI in response to a lengthening of the supply chain, one could in principle derive the results in a closed economy model with no international trade in intermediate goods. However, to study cross country heterogeneity in the PPI responses and to take into account observed data patterns in trade in intermediate goods, it becomes essential to use a multi-country multi-stage model.

There are three different types of parameters in the model: share parameters in the production functions $\{\theta, \alpha\}$, bilateral trade costs $\{\tau^{in}\}$ for $\forall i, n = 1, \ldots, N$, and location parameters $\{T^n_{g=1,\ldots,G}, T^n_s\}_{n=1}^N$ and shape parameter κ for the productivity distributions.

We use the World Input-Output Database (WIOD) in 1998 and 2005 to calibrate the model. The database covers 40 countries, including the most important economies in the world in terms of either GDP or volume of international trade. We use 1998 as a representative year for the pre-2001 period, and 2005 as a representative year for the post-2001 period. As a robustness check, we also use 1997 and 2006 as a representative year in the pre-2001 and post-2001 periods, respectively, and find the similar results.

7.1 Calibration

For the share parameters, since $1-\theta$ is the labor share in manufacturing production, it is set at $\theta = 0.67$ to match the median input share of manufactures following Johnson and Moxnes (2013). We set the median share of manufactures in final expenditure over all countries, α, to be 0.416 for 1998 and 0.402 for 2005, respectively.

The model assumes that the productivity in a given stage, sector, and country is independently drawn from a common Fréchet distribution, with a common shape parameter and different location parameters for different countries. Following Simonnovska and Waugh (2014), we set the shape parameter at $\kappa = 4.12$.

Note that, re-scaling the location parameters for all countries does not alter comparative advantages, and thus does not affect the quantity assignment in equilibrium, nor bilateral trade shares. Without loss of generality, we set the United States to be Country 1 and normalize its location parameters in each stage to be one, i.e., $T_g^1 = 1$ for $g = 1, \ldots, G$. In this sense, other country's technology parameters are measured relative to those of the United States. While the technology parameters in the manufacturing sector will be estimated from the observed bilateral trade shares in intermediate goods and final goods, we cannot do the same thing for the service sector productivity since service output is not directly traded. Instead, we assume the location parameter for service sector productivity in a given country to be a geometric average of the location parameters across all manufacturing stages in the same country, i.e., $T_s^n = exp[(\sum_{g=1}^{G} logT_g^n)/G]$ for $\forall n$. This implies that a country is assumed to be more productive in the service sector if its manufacturing is more productive on average. This assumption does not affect the estimated responses of either CPI or PPI to a first stage productivity shock.

We need some restrictions on the bilateral trade costs to keep the number of parameters manageable. Following Head and Ries (2001), we back out the bilateral trade costs by bilateral trade shares in final goods, i.e.,

$$(\tau^{in})^{-\kappa} = \sqrt{\frac{\hat{\pi_G^{in}}\hat{\pi_G^{ni}}}{\hat{\pi_G^{ii}}\hat{\pi_G^{nn}}}}$$

where π_G^{in} is the bilateral trade share in terms of final goods, i.e, the spending by country n on the final goods produced in country i divided by total spending of country n on final goods. Details on the construction of the bilateral trade shares are described later. This method of calibrating trade costs is also adopted in Antràs and De Gortari (2017).

To summarize, there are $G \cdot (N-1)$ number of location parameters for productivities that need to be backed out, and they are $\{T^n_{g=1,\ldots,G}\}^N_{n=2}$. To do so, we match the expenditure of country n in purchasing country i's intermediate and final goods, respectively, as a share of country n's total expenditure. The matching targets are defined as, for $\forall i, n$,

$$InterShare^{in} = (InterExpense^{in} / \sum_{i=1}^{N} InterExpense^{in})$$

$$FinalShare^{in} = (FinalExpense^{in} / \sum_{i=1}^{N} FinalExpense^{in})$$

For any specific values of $\{T^n_{g=1,\ldots,G}\}^N_{n=2}$, the model gives a matrix of bilateral trade shares in terms of final goods and intermediate goods. The parameter values are chosen to minimize the sum of the distances of bilateral trade shares between the model prediction and the data.

The first 19 sectors in WIOD are defined as "manufacturing activities" and aggregated into a single "manufacturing sector," while the remaining 16 service sectors are aggregated into a single "service sector." Since the final shares and intermediate shares for any country n sum up to one, there are $2(N^2 - N)$ moments. As long as $2(N^2 - N) \geq G(N-1)$, the model can be identified.[12]

The number of manufacturing production stages is exogenous in the model. As a baseline case, we set $G = 2$ for 1998, and $G = 3$ for 2005. As a robustness check, we also use $G = 4$ for 2005.[13] The model is over-identified in all cases.

Table 7 summarizes the calibration for parameters not estimated from bilateral trade shares, and Table 8 and 9 report the estimated results for productivity location parameters in 1998 and 2005, respectively.

We will estimate the model by the method of moments. As there are around one hundred parameters to be estimated in the nonlinear environment, one needs to search for a global optimum. We adopt a simulated-annealing algorithm in optimization (Bertsimas and Tsitsiklis, 1993), which introduces a probability of jumping out of local optimums, making

[12] When we estimate the bilateral trade shares predicted by the model, we use population data in 1998 and 2005 from the Penn World Table 9.0 to proxy for labor supply. Following Johnson and Moxnes (2013), we construct relative wages across countries by total household consumption (in WIOD) divided by total labor supply in the estimation.

[13] This is consistent with Antràs and De Gortari (2017). In addition, for the pre-2001 period, the case of $G = 1$ can be easily ruled out. If $G = 1$, the responses of PPI to the first-stage productivity shock would have been constant across countries (i.e., no variation across countries), which is obviously rejected by the data. Following Antràs and De Gortari (2017), we set $G = 2$ for the pre-2001 period. Since Wang et al. (2017) show that the production length is greater after 2001, we consider G=3 for the post-2001 period as the benchmark case. We have also conducted the calibration for the cases of $G = 2, 3$ and 4 for the post-2001 period, the results in Section 7.4 suggest that $G = 3$ for the post-2001 period is appropriate.

it more likely to reach a global optimum.

7.2 The log-deviation of CPI and PPI in response to manufacturing productivity shock

Given the calibrated parameters in this section, we generate the model-predicted responses of CPI and PPI inflation to a productivity shock in the first-stage of manufacturing production as shown in Equation 1 and 2. Table 10 shows the log-deviation of CPI and PPI in response to a first-stage productivity shock, and illustrates the $\Delta lnPPI/\Delta lnCPI$ ratio as the length of global value chain becomes larger.

From Table 10, as the number of production stages increases from 2 to 3, both the log-deviations of CPI and PPI become less responsive as illustrated in Column 1 and 3 of Table 10. In addition, the decline in sensitivity is greater for CPI than for PPI.[14] Specifically, as shown in Columns 1 and 3 of Table 10, the median of $\Delta lnPPI/\Delta lnCPI$ ratio increases from 2.408 in 1998 to 3.016 in 2005. These patterns are in line with the model predictions as in Proposition 2.

For robustness check, we also generate the model-predicted response of CPI and PPI inflation if $G = 4$ in 2005. Table 11 reports the estimated productivity location parameters in this case, and Table 12 reports the log-deviation of CPI and PPI in response to a first stage productivity shock, respectively. It is clear that, as the number of production stages increases, the log-deviations of both CPI and PPI become less responsive, and the median of $\Delta lnPPI/\Delta lnCPI$ ratio increases from 2.408 in 1998 to 2.997 in 2005.

7.3 The empirical country-specific CPI and PPI response to changes in global industrial input prices

We next explore cross-country heterogeneity in the response of CPI and PPI inflation to changes in global industrial input prices. Specifically, we construct specifications for Equation 1 and 2 that allow for potentially different sensitivity of CPI and PPI to industrial input prices for different countries.

$$\Delta lnCPI_t^n = \beta_1 \cdot \Delta CPI_{t-1}^n + \beta_2^n \cdot I^n \cdot \Delta lnP_{Industrial,t}^n + X_t^n + \epsilon_{CPI,t}^n$$

$$\Delta lnPPI_t^n = \gamma_1 \cdot \Delta lnPPI_{t-1}^n + \gamma_2^n \cdot I^n \cdot \Delta lnP_{Industrial,t}^n + X_t^n + \epsilon_{PPI,t}^n$$

where I^n is a country dummy variable and X_t^n indicates other control variables including log-change in wage per hour and country fixed effects. All the variables are denominated in

[14] From the model, we know that, subject to the first-stage productivity shock, $\Delta lnCPI$ is the same across countries while $\Delta lnPPI$ is heterogeneous.

nominal terms and local currency.[15]

Figure 9 shows the distribution of the estimated CPI and PPI elasticities to industrial input prices for those countries included in WIOD. Comparing the sub-figures between Column 1 and 2 in Figure 9, both of the CPI and PPI elasticities decrease after 2001. In addition, for the pre-2001 period, the dispersion of CPI elasticity across countries, measured by standard derivation, is 0.165, and the dispersion of PPI elasticity is 0.266; for the post-2001 period, the dispersion of CPI elasticity is 0.038, and the dispersion of PPI elasticity is 0.074. In other words, the country heterogeneity is much larger for PPI elasticity to industrial input price compared with CPI, and the heterogeneity for both CPI and PPI decreases after 2001.

7.4 Model calibrations versus empirical results

Taking calibration and empirics together, we now explore country-specific predictions from the model and the heterogeneous estimated coefficients from the empirics.

Table 13 reports the correlation between the model-calibrated and empirically estimated PPI elasticities. It also includes the p-value for the one-sided T-test under the null hypothesis that the correlation between calibration results and empirical estimations is no greater than zero.[16] In Column 1 of Table 13, we calibrate PPI elasticities across countries using 1998 data with the assumption of $G = 2$, and empirically estimate PPI elasticities in the pre-2001 sample that allow for cross-country heterogeneity as showed in Subsection 7.3. The correlation between the calibration results and empirics is 0.441, and it is significantly greater than zero with a p-value 0.9%. This means that the cross-country heterogeneity in the empirical elasticity of PPI response to global shocks in industrial input prices is in line with the model predictions in terms of cross-country heterogeneity. We emphasize again that, this test is quite demanding since the model calibrations and empirical regressions draw on two completely different (in fact, non-overlapping) sets of data - the former on the input-output relations in WIOD and bilateral trade data, whereas the latter on nationally reported PPI statistics and IMF-reported global industrial input prices.

Column 3 in Table 13 presents the calibrated PPI elasticities across countries (under the assumption of $G = 3$ and using the 2005 world input-output table) against the empirically

[15] We adopt LSDV estimators for the regressions incorporating country-specific CPI and PPI responses. On the one hand, the estimators for dynamic panel data like QML do not apply here. From econometric theory aspect, the asymptotic assumptions for those dynamic panel estimators (i.e., given finite time periods T, the number of groups N goes to infinity) does not hold. For the specific regressions in this subsection, if N goes to infinity, the number of independent variables goes to infinity, which makes the estimators not applicable. On the other hand, since we are interested in PPI responses, and, as showed in the tables in Section 6, the autocorrelation for PPI is very weak, the LSDV estimator will not generate strong bias. In addition, we have also done the estimations using the corrected LSDV estimators (Judson and Owen, 1999), and the results are robust.

[16] In calculating the correlation, we exclude the countries whose empirically estimated elasticities are not significant (at the 10% level), and outliers. The maximum number of exclusions is four.

estimated post-2001 PPI elasticities. The correlation between the calibrated and empirically estimated elasticities is 0.388, and it is significantly greater than zero with a p-value 1.0%.

Furthermore, to show that use of other years in the neighborhood in calibration would not materially alter our inference, we also adopt the data in 1997 for the pre-2001 period with the assumption of $G = 2$, and 2006 for the post-2001 period with the assumption of $G = 3$ to calibrate the model. Column 2 and 4 show the correlation between the calibrated PPI elasticities by the model and the empirically estimated elasticities for these two cases, respectively. Similar pattern follows, and we obtain a statistically significant positive correlation, i.e., 0.498, with a p-value 0.3% for the pre-2001 period, and a statistically significant positive correlation, i.e., 0.328, with a p-value 2.6% for the post-2001 period.

Given the increase in production length, a robustness check we perform is to assume $G = 4$ in the post-2001 period. Column 5 in Table 13 reports the correlation between the model-calibrated PPI elasticities (using the 2005 world input-output table under the assumption of $G = 4$) and the empirically estimated post-2001 PPI elasticities. Even though the correlation is not statistically significant, it is still positive.[17]

To clarify, even though the discussion in this section could shed light on the choice of total number of stages, our focus is not on estimating the appropriate value of G. Instead, we take as given that G has increased from the pre-2001 period to the post-2001 period (as shown in Antràs and De Gortari, 2017; and Wang et al., 2017). We emphasize insight from cross-country heterogeneity, and check whether the empirical data patterns at the level of individual countries are consistent with the model predictions.

To summarize, in spite of the fact that the two sets of PPI elasticities from the model calibrations and from empirical estimation, respectively, draw on two different data sets, the patterns of cross-country heterogeneity, i.e., which countries' PPIs are more responsive to global shocks in industrial input prices, are in line with each other. We take this as evidence that the model is informative and useful.

8 Concluding remarks

When PPI and CPI diverge, as they did since 2001, the optimal Taylor rule in the monetary economics may need to be revised. This paper proposes that a rise in global value chains can be an important factor behind the observed divergence between PPI and CPI inflation. The key idea is that, as the vertical fragmentation become stronger, i.e., there are more stages in the production process, more intermediate goods enter international trade and national PPI basket. As a result, the common component in the two price indexes (i.e., domestic

[17] We also perform the calibration by assuming $G = 2$ in the post-2001 period. The correlation between the model-calibrated PPI elasticities and the empirically estimated PPI elasticities is 0.273 with a p-value 5.4%. In comparison, in Columns 3 and 5 in Table 13, the case of $G = 3$ gives a higher correlation with the lowest p-value. In other words, $G = 3$ appears to be preferred by the data for the post-2001 period.

consumed final goods which are also domestically produced) becomes a smaller part of the PPI basket. This means that the divergence between the two price indices is at least in part driven by a fundamental force (increasing segmentation of the production process).

We build a multiple-production-stage version of the Eaton-Kortrum model to illustrate this intuition, and take the model predictions to the data. We find several pieces of empirical support. First, by using industrial input price as a proxy for upstream productivity shocks, we find that both CPI and PPI inflation become less responsive to the industrial input price shock in the post-2001 sample than in the pre-2001 sample. Second, the reduction in the sensitivity is greater for CPI than for PPI. These patterns are consistent with the model predictions. The results are also robust from controlling for labor cost, price index level, and nominal exchange rate changes.

Third, we attempt a more demanding exercise by examining cross-country heterogeneity in the PPI responses to global industrial input price changes (among 40 countries covered in the WIOD). From the model, observed bilateral trade shares in intermediate goods are used to back out realizations of productivity shocks at every stage of production in each country. They are then used to calibrate model-implied PPI responses to a global shock to the first-stage productivity in the manufacturing production, which differ across countries. From nationally reported PPI series, we separately estimate country-specific PPI responsiveness to changes in the global input price index. Putting the two together, we find that the model-implied and empirically PPI elasticities are in line with each other.

It is worth noting that the story proposed in this paper about the divergence between CPI and PPI inflation can be told in a closed-economy setting. Nevertheless, the observed increase in segmentation of production after 2001 has been greatly facilitated by offshoring and international trade, including the rise of China and Eastern Europe as a platform for production and exports. Indeed, the patterns documented in Wang et al. (2017) suggests that a major part of the increase in global production length is an increase in the length of the cross-border part of production. In any case, an open-economy model is more general than a closed-economy model. For these reasons, the main results in the paper can be viewed as implications of a rise in global value chains for inflation indices.

In addition, the model is solved by using tools from the international trade field (a multi-stage extension of the Eaton-Koturm model in particular). In this sense, the paper can be viewed as insight from economics of international trade for monetary economics.

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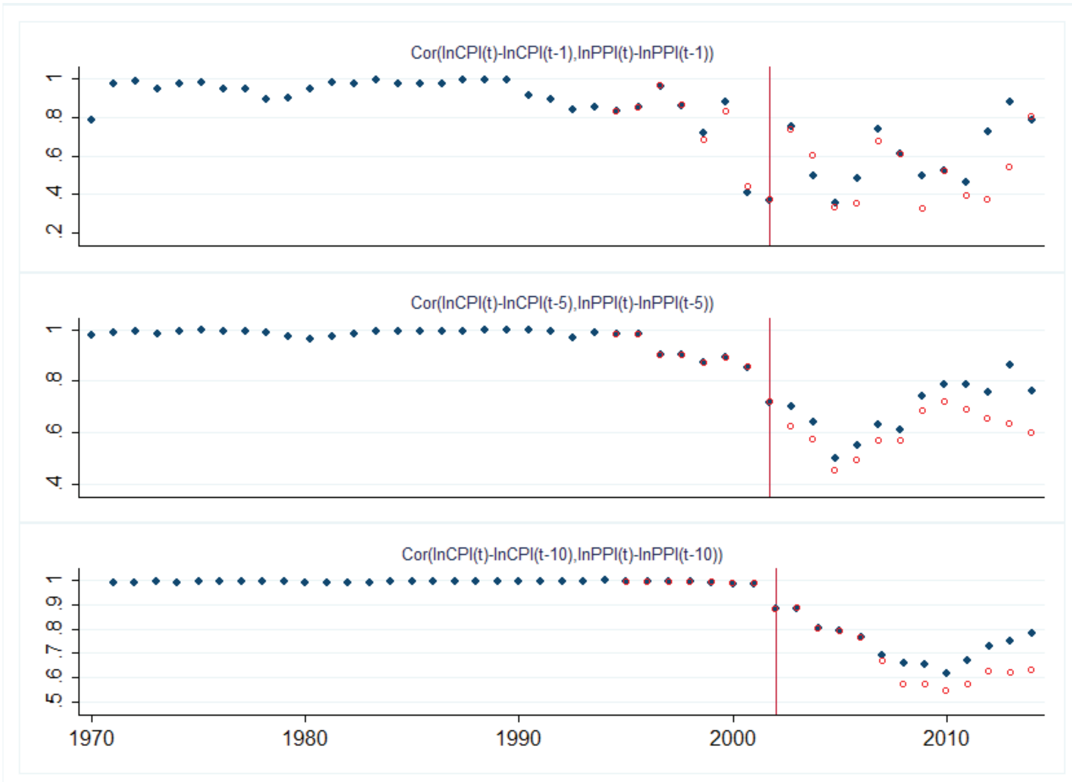

Figure 1: The correlation between CPI and PPI over time

Notes: The top panel presents the correlation of the annual percentage changes of the two variables during the period; the middle panel presents the correlation of the two in terms of changes over 5-years; the bottom panel gives the correlation in terms of changes over 10-years. Each blue dot in this figure is the cross-sectional correlation of CPI and PPI inflation in a given year across all countries with available data. The red circles represent a constant sample since 1995, i.e., a (maximum) common set of countries since 1995. The red vertical line represents the year of 2002.

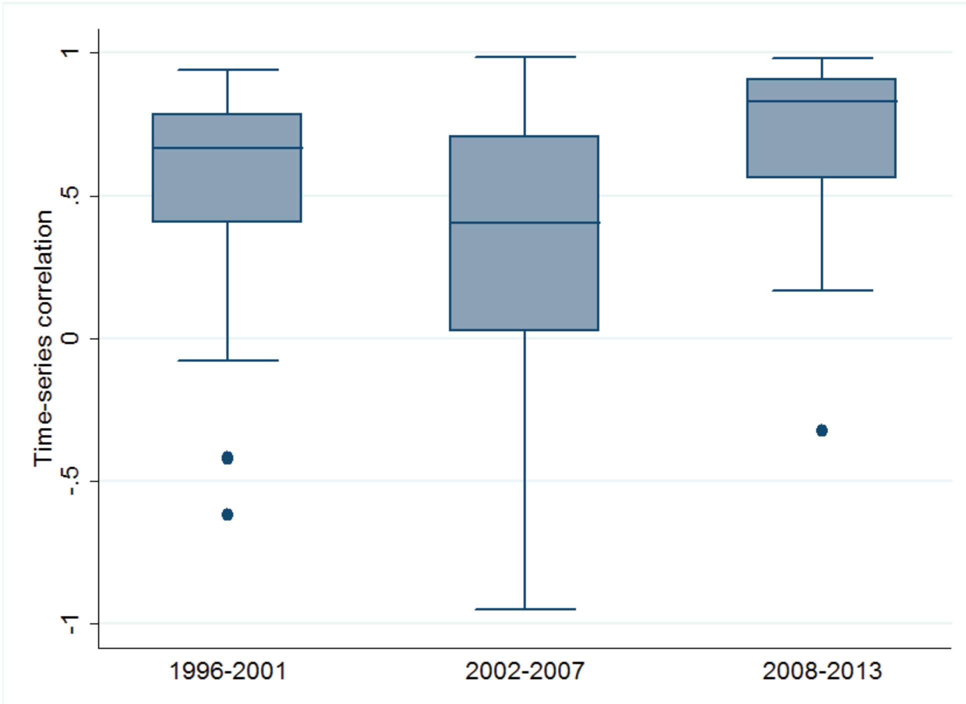

Figure 2: Time-series correlations across high-income countries, constant sample since 1995

Notes: This figure displays the cross-country distributions of the country-specific time-series correlation between CPI and PPI inflation for the three periods among high-income countries (defined by World Bank 2017). For comparability, we use the common set of countries for all three time periods, and thus 37 countries are included in the sample.

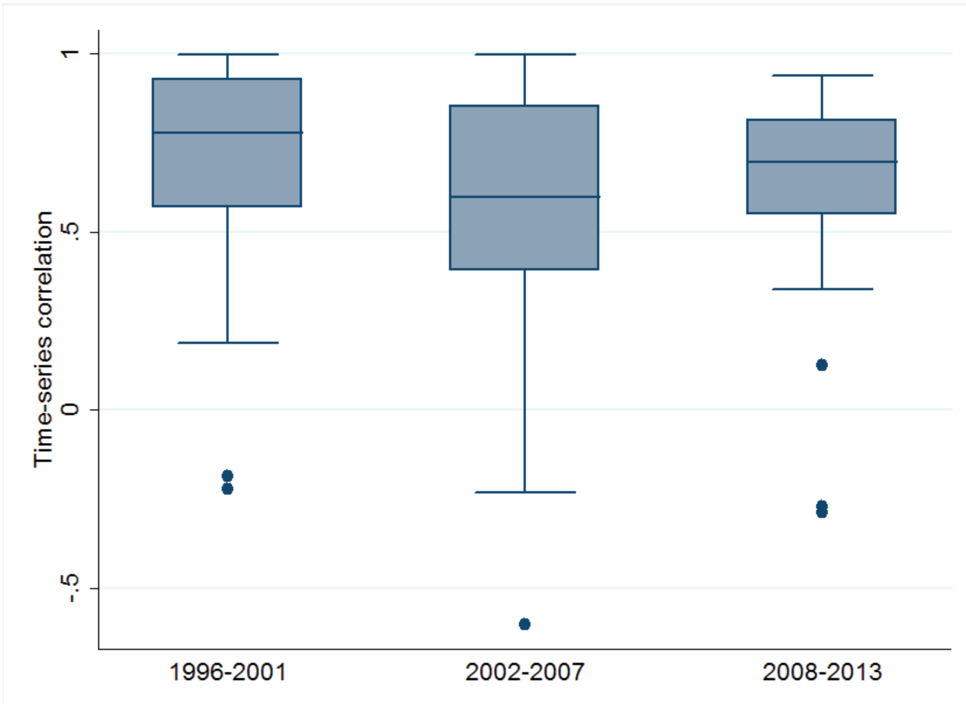

Figure 3: Time-series correlations across developing countries, constant sample since 1995

Notes: This figure displays the cross-country distributions of the country-specific time-series correlation between CPI and PPI inflation for the three periods among developing countries (consisting both of middle-income and low-income countries, defined by World Bank 2017). For comparability, we use the common set of countries for all three time periods, and thus 26 countries are included in the sample.

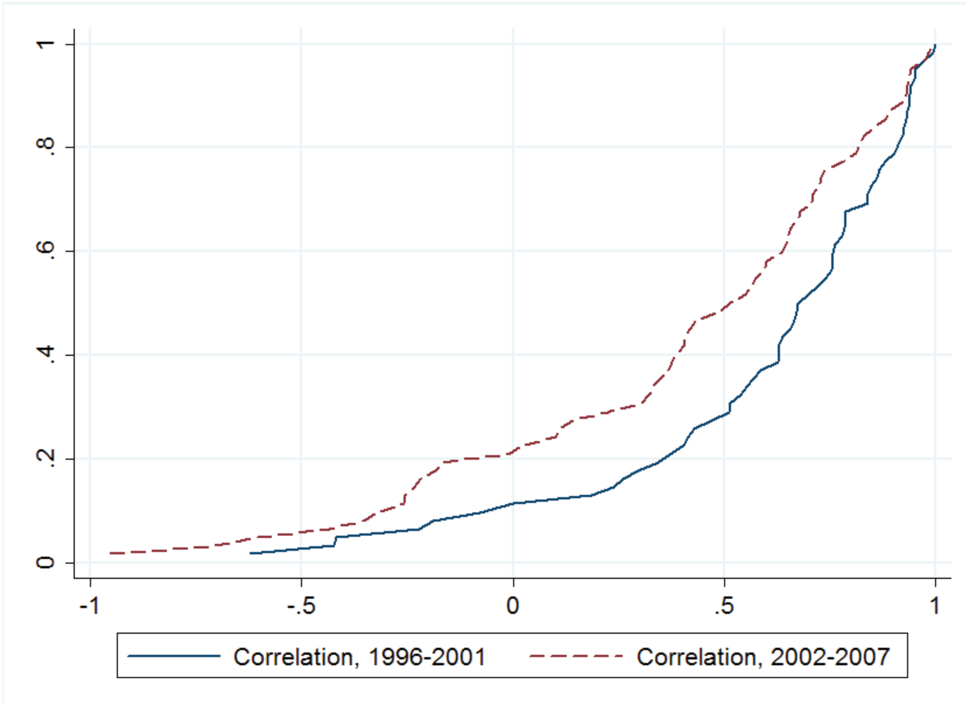

Figure 4: Cumulative distribution of 6-year time-series correlation, constant sample since 1995

Notes: This figure displays the cumulative distribution of the 6-year country-specific time-series correlations across countries for the pre-2001 and post-2001 periods. For comparability, we keep constant set of countries.

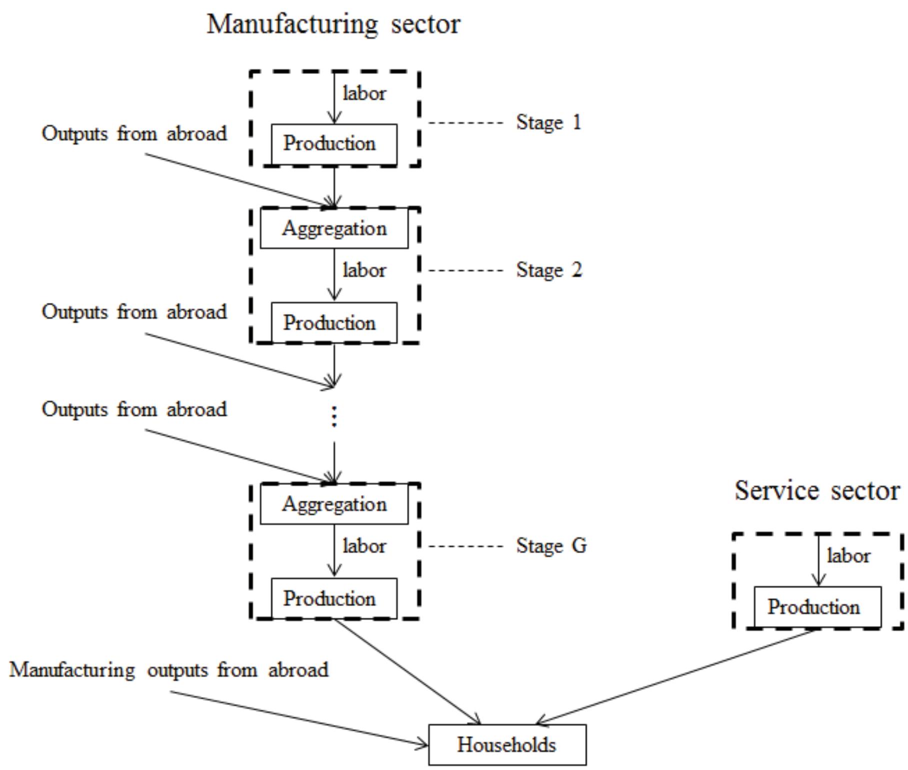

Figure 5: Production structure

Notes: This figure illustrates the production process of the manufacturing and service sectors for a country in the model.

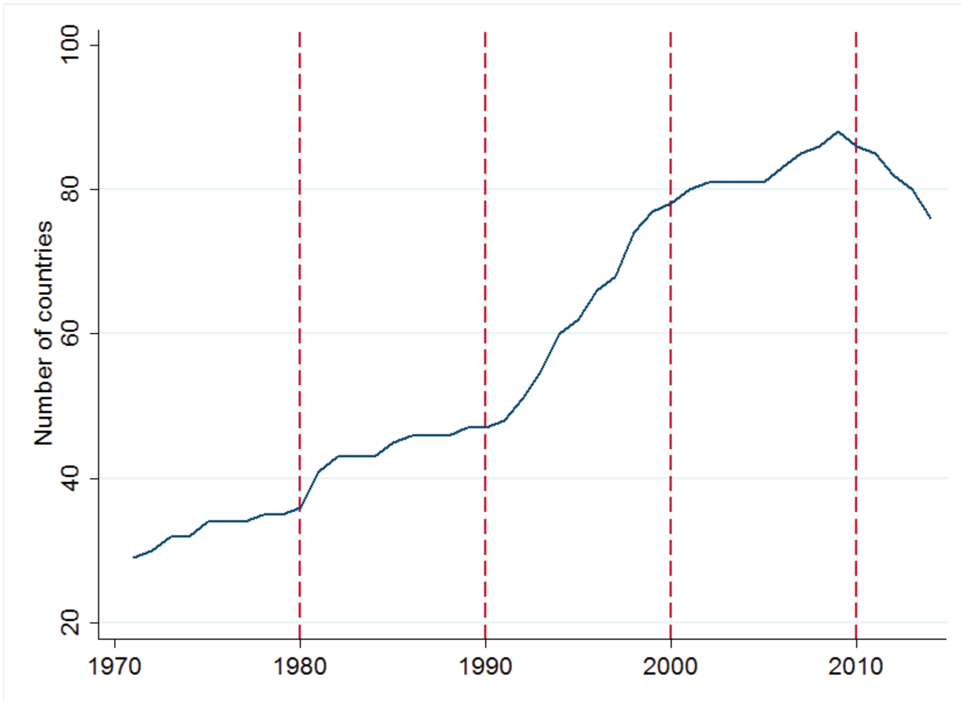

Figure 6: The number of countries with CPI and PPI data available

Notes: This figure displays the number of countries for which both CPI and PPI data are available in each year. The red dotted lines represent the year of 1980, 1990, 2000, and 2010, respectively.

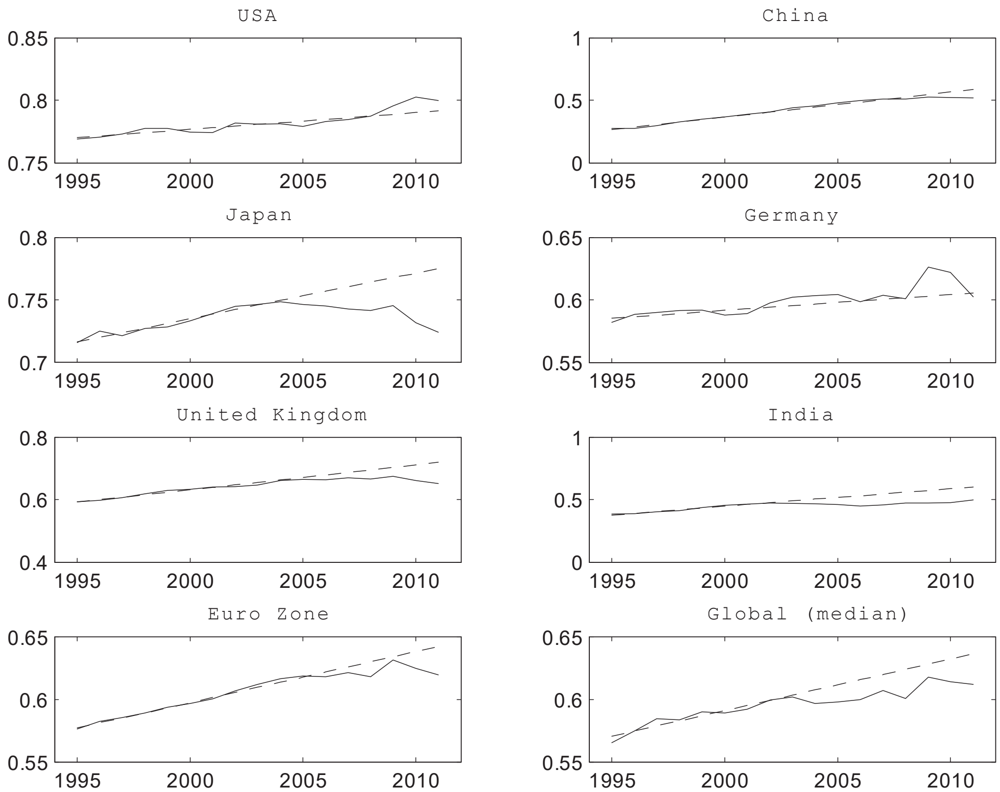

Figure 7: Service share in household consumption, WIOD

Notes: This figure displays the expenditure share of services in the consumption basket for WIOD countries. The dashed lines represent a country-specific trend constructed from the data by using the period from 1995 to 2001. The sub-figure labeled as "global" indicates all the countries included in WIOD dataset.

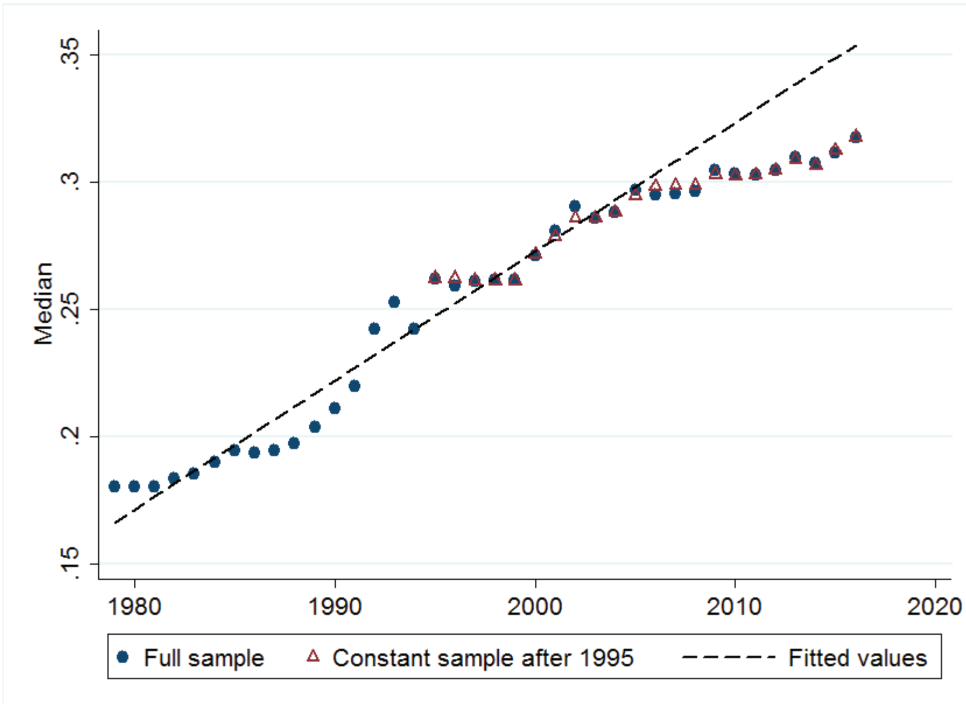

Figure 8: Weight of service less housing in CPI (median), OECD

Notes: This figure displays the median share of services (excluding housing) in the CPI basket for OECD countries (from OECD dataset). The blue dots represent the median of all countries with data available in OECD dataset. The red triangles represent the case with keeping constant samples after 1995. The dashed line is fitted by median values of service share in the full sample from 1980 to 2001.

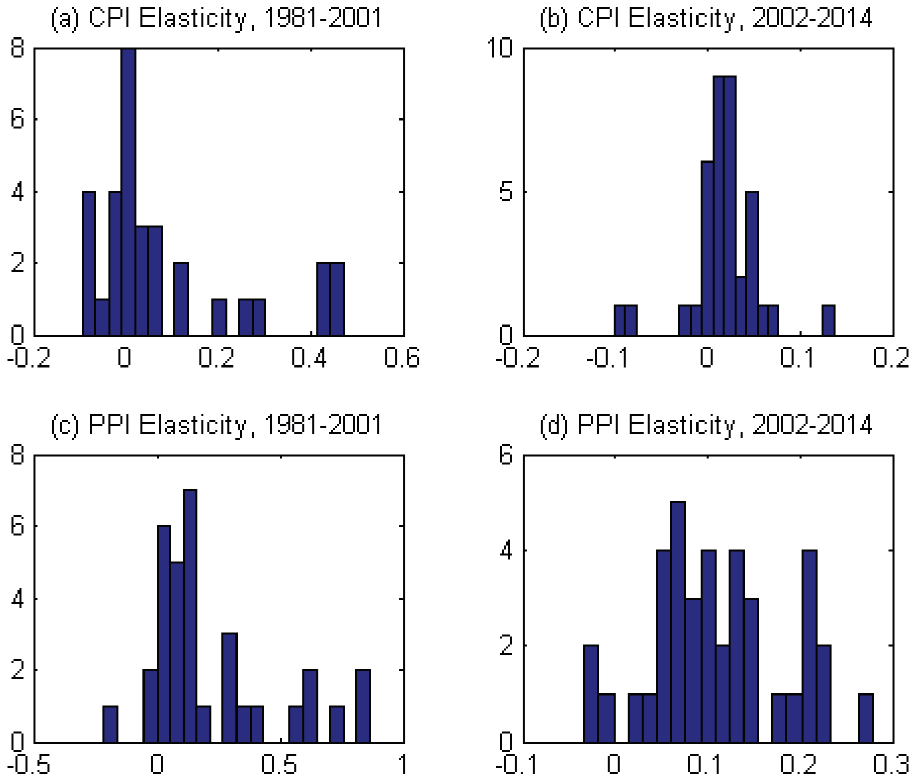

Figure 9: The histogram of CPI and PPI elasticities to industrial input price, WIOD countries

Notes: This figure displays the distribution of the empirically estimated CPI and PPI elasticities to industrial input prices for those countries included in WIOD with the pre-2001 and post-2001 periods, respectively.

Table 1: The response of CPI and PPI inflation to industrial input price

VARIABLES	(1) lnCPI 1981-2001	(2) lnPPI 1981-2001	(3) lnCPI 2002-2014	(4) lnPPI 2002-2014	(5) lnCPI 2002-2014	(6) lnPPI 2002-2014
$\Delta lnP_{Industrial,t}$	0.557***	0.743***	0.034***	0.160***	0.043***	0.170***
	(0.106)	(0.094)	(0.009)	(0.020)	(0.010)	(0.022)
$\Delta lnCPI_{t-1}$	0.329***		0.471***		0.504***	
	(0.062)		(0.073)		(0.078)	
$\Delta lnPPI_{t-1}$		0.170**		0.173***		0.218***
		(0.067)		(0.055)		(0.053)
$Year2008$					0.047***	0.090***
					(0.004)	(0.009)
$Year2009$					-0.021***	-0.057***
					(0.005)	(0.010)
# Obs.	1,459	883	1,407	1,046	1,407	1,046
Ratio of Response (R)	1.334		4.706		3.953	
$R_{post,2001} - R_{pre,2001}$			3.372		2.619	
P-value, $H0: \Delta R \leq 0$			0.1%		0.2%	

Notes: This table estimates the responses of CPI and PPI inflation to changes in industrial input prices. The quasi-maximum likelihood (QML) estimators for dynamic panel data are adopted. Country fixed effects have been controlled (i.e., QML with fixed effects). Variable $Year2008$ equals 1 if the observation is in the year of 2008; otherwise, 0. Variable $Year2009$ equals 1 if the observation is in the year of 2009; otherwise, 0. Variable, Ratio of Response, is the ratio of the coefficient of PPI inflation in response to industrial input price change divided by the coefficient of CPI inflation in response to industrial input price change, i.e., $\frac{\partial \Delta lnPPI_t / \partial \Delta lnP_{Industrial,t}}{\partial \Delta lnCPI_t / \partial \Delta lnP_{Industrial,t}}$. Country-clustered robust standard errors are reported in parentheses. *** denotes $p < 0.01$, ** denotes $p < 0.05$, while * denotes $p < 0.1$.

Table 2: The response of CPI and PPI inflation to industrial input price with controlling nominal wage

VARIABLES	(1) lnCPI 1981-2001	(2) lnPPI 1981-2001	(3) lnCPI 2002-2014	(4) lnPPI 2002-2014	(5) lnCPI 2002-2014	(6) lnPPI 2002-2014
$\Delta lnP_{Industrial,t}$	0.412***	0.425***	0.031***	0.157***	0.042***	0.170***
	(0.142)	(0.075)	(0.009)	(0.021)	(0.010)	(0.023)
$\Delta lnCPI_{t-1}$	0.233***		0.442***		0.482***	
	(0.046)		(0.067)		(0.074)	
$\Delta lnPPI_{t-1}$		0.053		0.158***		0.209***
		(0.061)		(0.049)		(0.048)
$WageDummy * \Delta lnwage_t$	0.456***	0.537***	0.178***	0.241***	0.114***	0.127*
	(0.141)	(0.087)	(0.030)	(0.085)	(0.028)	(0.074)
$Year2008$					0.046***	0.089***
					(0.004)	(0.009)
$Year2009$					-0.019***	-0.055***
					(0.005)	(0.009)
# Obs.	1,459	883	1,407	1,046	1,407	1,046
Ratio of Response (R)	1.032		5.065		4.048	
$R_{post,2001} - R_{pre,2001}$			4.033		3.016	
P-value, $H0: \Delta R \leq 0$			1.6%		2.3%	

Notes: This table estimates the responses of CPI and PPI inflation to changes in industrial input prices. The quasi-maximum likelihood (QML) estimators for dynamic panel data are adopted. Country fixed effects have been controlled (i.e., QML with fixed effects). Variable, $WageDummy * \Delta lnwage_t$, equals $\Delta lnwage_t$ if wage data are available; otherwise, 0. Variable $Year2008$ equals 1 if the observation is in the year of 2008; otherwise, 0. Variable $Year2009$ equals 1 if the observation is in the year of 2009; otherwise, 0. Variable, Ratio of Response, is the ratio of the coefficient of PPI inflation in response to industrial input price change divided by the coefficient of CPI inflation in response to industrial input price change, i.e., $\frac{\partial \Delta lnPPI_t / \partial \Delta lnP_{Industrial,t}}{\partial \Delta lnCPI_t / \partial \Delta lnP_{Industrial,t}}$. Country-clustered robust standard errors are reported in parentheses. *** denotes $p < 0.01$, ** denotes $p < 0.05$, while * denotes $p < 0.1$.

Table 3: The response of CPI and PPI inflation to industrial input price with controlling nominal wage and price index level

VARIABLES	(1) lnCPI 1981-2001	(2) lnPPI 1981-2001	(3) lnCPI 2002-2014	(4) lnPPI 2002-2014	(5) lnCPI 2002-2014	(6) lnPPI 2002-2014
$\Delta lnP_{Industrial,t}$	0.397***	0.428***	0.032***	0.138***	0.042***	0.153***
	(0.130)	(0.077)	(0.009)	(0.016)	(0.010)	(0.019)
$\Delta lnCPI_{t-1}$	0.233***		0.434***		0.474***	
	(0.044)		(0.062)		(0.069)	
$\Delta lnPPI_{t-1}$		0.053		0.120***		0.175***
		(0.062)		(0.045)		(0.043)
$lnCPI_{t-1}$	-0.010***		0.004		0.005	
	(0.004)		(0.006)		(0.006)	
$lnPPI_{t-1}$		-0.002		-0.017		-0.015
		(0.005)		(0.012)		(0.011)
$WageDummy * \Delta lnwage_t$	0.443***	0.523***	0.160***	0.202***	0.106***	0.101*
	(0.128)	(0.083)	(0.030)	(0.058)	(0.029)	(0.054)
$Year2008$					0.046***	0.087***
					(0.004)	(0.009)
$Year2009$					-0.019***	-0.054***
					(0.005)	(0.010)
# Obs.	1,448	881	1,407	1,046	1,407	1,046
Ratio of Response (R)	1.078		4.313		3.643	
$R_{post,2001} - R_{pre,2001}$			3.235		2.565	
P-value, $H0: \Delta R \leq 0$			1.6%		2.4%	

Notes: This table estimates the responses of CPI and PPI inflation to changes in industrial input prices. The quasi-maximum likelihood (QML) estimators for dynamic panel data are adopted. Country fixed effects have been controlled (i.e., QML with fixed effects). Variable, $WageDummy * \Delta lnwage_t$, equals $\Delta lnwage_t$ if wage data are available; otherwise, 0. Variable $Year2008$ equals 1 if the observation is in the year of 2008; otherwise, 0. Variable $Year2009$ equals 1 if the observation is in the year of 2009; otherwise, 0. Variable, Ratio of Response, is the ratio of the coefficient of PPI inflation in response to industrial input price change divided by the coefficient of CPI inflation in response to industrial input price change, i.e., $\frac{\partial \Delta lnPPI_t / \partial \Delta lnP_{Industrial,t}}{\partial \Delta lnCPI_t / \partial \Delta lnP_{Industrial,t}}$. Country-clustered robust standard errors are reported in parentheses. *** denotes $p < 0.01$, ** denotes $p < 0.05$, while * denotes $p < 0.1$.

Table 4: The response of CPI and PPI inflation to industrial input price with exchange rate

VARIABLES	(1) lnCPI 1981-2001	(2) lnPPI 1981-2001	(3) lnCPI 2002-2014	(4) lnPPI 2002-2014	(5) lnCPI 2002-2014	(6) lnPPI 2002-2014
$\Delta lnP_{Industrial,t}$ (USD)	0.080***	0.198***	0.026***	0.155***	0.028***	0.150***
	(0.022)	(0.049)	(0.007)	(0.016)	(0.007)	(0.015)
$\Delta lnCPI_{t-1}$	0.214***		0.432***		0.479***	
	(0.044)		(0.064)		(0.071)	
$\Delta lnPPI_{t-1}$		0.047		0.156***		0.200***
		(0.056)		(0.047)		(0.046)
$\Delta lnExchangeRate_t$	0.491***	0.532***	0.065**	0.189***	0.099***	0.243***
	(0.151)	(0.079)	(0.030)	(0.057)	(0.032)	(0.061)
$WageDummy * \Delta lnwage_t$	0.400***	0.441***	0.188***	0.263***	0.125***	0.151**
	(0.138)	(0.091)	(0.029)	(0.079)	(0.026)	(0.067)
$Year2008$					0.045***	0.089***
					(0.004)	(0.009)
$Year2009$					-0.027***	-0.065***
					(0.005)	(0.010)
# Obs.	1,459	883	1,407	1,046	1,407	1,046
Ratio of Response (R)	2.475		5.962		5.357	
$R_{post,2001} - R_{pre,2001}$			3.487		2.882	
P-value, $H0: \Delta R \leq 0$			1.1%		1.5%	

Notes: This table estimates the responses of CPI and PPI inflation to changes in industrial input prices. The quasi-maximum likelihood (QML) estimators for dynamic panel data are adopted. Country fixed effects have been controlled (i.e., QML with fixed effects). Variable, $WageDummy * \Delta lnwage_t$, equals $\Delta lnwage_t$ if wage data are available; otherwise, 0. Variable $Year2008$ equals 1 if the observation is in the year of 2008; otherwise, 0. Variable $Year2009$ equals 1 if the observation is in the year of 2009; otherwise, 0. Variable, Ratio of Response, is the ratio of the coefficient of PPI inflation in response to industrial input price change divided by the coefficient of CPI inflation in response to industrial input price change, i.e., $\frac{\partial \Delta lnPPI_t / \partial \Delta lnP_{Industrial,t}}{\partial \Delta lnCPI_t / \partial \Delta lnP_{Industrial,t}}$. Country-clustered robust standard errors are reported in parentheses. *** denotes $p < 0.01$, ** denotes $p < 0.05$, while * denotes $p < 0.1$.

Table 5: The response of CPI and PPI inflation to commodity price

VARIABLES	(1) lnCPI 1993-2001	(2) lnPPI 1993-2001	(3) lnCPI 2002-2014	(4) lnPPI 2002-2014	(5) lnCPI 2002-2014	(6) lnPPI 2002-2014
$\Delta lnP_{Commodity,t}$	0.427***	0.694***	0.093***	0.258***	0.073***	0.240***
	(0.119)	(0.140)	(0.010)	(0.029)	(0.015)	(0.035)
$\Delta lnCPI_{t-1}$	0.319***		0.605***		0.575***	
	(0.047)		(0.049)		(0.052)	
$\Delta lnPPI_{t-1}$		0.089		0.175***		0.150***
		(0.127)		(0.052)		(0.053)
$Year2008$					0.031***	0.036***
					(0.004)	(0.006)
$Year2009$					-0.006	-0.000
					(0.007)	(0.013)
# Obs.	684	438	1,384	1,023	1,384	1,023
Ratio of Response (R)	1.625		2.774		3.288	
$R_{post,2001} - R_{pre,2001}$			1.149		1.663	
P-value, $H0: \Delta R \leq 0$			2.0%		1.8%	

Notes: This table estimates the responses of CPI and PPI inflation to changes in commodity prices. The quasi-maximum likelihood (QML) estimators for dynamic panel data are adopted. Country fixed effects have been controlled (i.e., QML with fixed effects). Variable $Year2008$ equals 1 if the observation is in the year of 2008; otherwise, 0. Variable $Year2009$ equals 1 if the observation is in the year of 2009; otherwise, 0. Variable, Ratio of Response, is the ratio of the coefficient of PPI inflation in response to industrial input price change divided by the coefficient of CPI inflation in response to industrial input price change, i.e., $\frac{\partial \Delta lnPPI_t / \partial \Delta lnP_{Commodity,t}}{\partial \Delta lnCPI_t / \partial \Delta lnP_{Commodity,t}}$. Country-clustered robust standard errors are reported in parentheses. *** denotes $p < 0.01$, ** denotes $p < 0.05$, while * denotes $p < 0.1$.

Table 6: The response of CPI and PPI inflation to commodity price with controlling nominal wage and price index level

VARIABLES	(1) lnCPI 1993-2001	(2) lnPPI 1993-2001	(3) lnCPI 2002-2014	(4) lnPPI 2002-2014	(5) lnCPI 2002-2014	(6) lnPPI 2002-2014
$\Delta lnP_{Commodity,t}$	0.218***	0.352***	0.091***	0.244***	0.076***	0.228***
	(0.057)	(0.073)	(0.010)	(0.026)	(0.015)	(0.032)
$\Delta lnCPI_{t-1}$	0.189***		0.551***		0.530***	
	(0.056)		(0.042)		(0.046)	
$\Delta lnPPI_{t-1}$		-0.027		0.145***		0.129***
		(0.106)		(0.047)		(0.046)
$lnCPI_{t-1}$	-0.053***		0.008		0.005	
	(0.018)		(0.005)		(0.005)	
$lnPPI_{t-1}$		-0.148***		-0.004		-0.008
		(0.050)		(0.011)		(0.011)
$WageDummy * \Delta lnwage_t$	0.553***	0.445***	0.106***	0.127**	0.096***	0.114**
	(0.090)	(0.131)	(0.023)	(0.060)	(0.023)	(0.058)
$Year2008$					0.030***	0.036***
					(0.004)	(0.006)
$Year2009$					-0.002	-0.000
					(0.006)	(0.012)
# Obs.	683	437	1,384	1,023	1,384	1,023
Ratio of Response (R)	1.615		2.681		3.000	
$R_{post,2001} - R_{pre,2001}$			1.066		1.385	
P-value, $H0: \Delta R \leq 0$			5.9%		4.6%	

Notes: This table estimates the responses of CPI and PPI inflation to changes in commodity prices. The quasi-maximum likelihood (QML) estimators for dynamic panel data are adopted. Country fixed effects have been controlled (i.e., QML with fixed effects). Variable, $WageDummy * \Delta lnwage_t$, equals $\Delta lnwage_t$ if wage data are available; otherwise, 0. Variable $Year2008$ equals 1 if the observation is in the year of 2008; otherwise, 0. Variable $Year2009$ equals 1 if the observation is in the year of 2009; otherwise, 0. Variable, Ratio of Response, is the ratio of the coefficient of PPI inflation in response to industrial input price change divided by the coefficient of CPI inflation in response to industrial input price change, i.e., $\frac{\partial \Delta lnPPI_t / \partial \Delta lnP_{Commodity,t}}{\partial \Delta lnCPI_t / \partial \Delta lnP_{Commodity,t}}$. Country-clustered robust standard errors are reported in parentheses. *** denotes $p < 0.01$, ** denotes $p < 0.05$, while * denotes $p < 0.1$.

Table 7: Calibration of some parameters

	Value	Source/Target
θ	0.67	Median input share for manufactures following Johnson and Moxnes (2013)
κ	4.12	Following Simonnovska and Waugh (2014)
α	0.416	Median manufactures in household consumption in WIOD, 1998
	0.402	Median manufactures in household consumption in WIOD, 2005
G	2	For the year of 1998
	3	For the year of 2005

Table 8: Calibration of two-stage location parameters using 1998 data

	Stage 1	Stage 2
Australia	0.489	0.392
Austria	0.637	0.714
Belgium	1.220	0.853
Bulgaria	1.074	1.026
Brazil	0.689	0.714
Canada	1.177	0.715
China	1.096	0.131
Cyprus	1.132	0.914
Czech Republic	0.491	0.967
Germany	0.932	0.806
Denmark	1.199	1.049
Spain	1.083	0.765
Estonia	1.525	0.925
Finland	0.768	0.775
France	1.208	1.024
United Kingdom	1.360	1.043
Greece	1.456	0.861
Hungary	1.223	0.878
India	1.250	0.274
Indonesia	1.014	0.222
Ireland	0.572	1.066
Italy	1.314	0.468
Japan	0.893	1.039
Korea	1.454	1.173
Lithuania	0.958	0.560
Luxembourg	1.414	0.849
Latvia	0.966	0.919
Mexico	1.223	0.721
Malta	1.395	0.941
Netherlands	1.313	1.074
Poland	0.730	0.790
Portugal	1.010	0.561
Romania	1.160	0.562
Russian Federation	1.482	0.347
Slovakia	1.480	0.881
Slovenia	1.354	1.065
Sweden	0.312	1.082
Turkey	1.297	0.898
Taiwan	1.265	0.893
United States	1.000	1.000

Note: The table reports the geometric mean of the Fréchet distribution, i.e., $exp(\gamma/\kappa)(T_g^n)^{1/\kappa}$, where γ is the Euler-Mascheroni constant. It is a monotonic transformation of productivity location parameters measuring average technology.

Table 9: Calibration of three-stage location parameters using 2005 data

	Stage 1	Stage 2	Stage 3
Australia	1.076	0.469	0.718
Austria	1.964	0.982	0.832
Belgium	2.250	1.117	0.935
Bulgaria	2.772	0.753	1.742
Brazil	2.001	1.305	1.861
Canada	2.221	1.325	1.665
China	2.727	0.250	1.092
Cyprus	2.622	1.127	1.621
Czech Republic	2.330	0.953	2.097
Germany	2.161	1.155	1.550
Denmark	2.216	1.028	1.761
Spain	2.362	0.909	1.900
Estonia	2.262	0.866	2.011
Finland	1.922	1.201	1.693
France	1.800	0.587	1.895
United Kingdom	2.091	0.894	1.540
Greece	2.032	0.716	0.954
Hungary	2.994	0.924	1.640
India	3.064	0.436	1.163
Indonesia	2.484	0.086	1.554
Ireland	2.339	1.221	1.563
Italy	1.755	0.651	0.912
Japan	1.355	1.008	1.307
Korea	1.836	0.695	1.172
Lithuania	1.612	0.641	1.824
Luxembourg	2.657	1.266	1.621
Latvia	2.698	0.814	2.002
Mexico	2.515	1.017	1.568
Malta	1.628	1.245	1.126
Netherlands	1.890	0.936	1.345
Poland	2.664	0.983	1.416
Portugal	2.484	0.891	1.622
Romania	2.537	0.689	1.343
Russian Federation	2.006	1.063	1.315
Slovakia	1.785	1.080	2.090
Slovenia	1.982	1.050	1.399
Sweden	2.153	1.045	1.715
Turkey	2.609	1.183	1.754
Taiwan	2.527	1.199	1.514
United States	1.000	1.000	1.000

Note: The table reports the geometric mean of the Fréchet distribution, i.e., $exp(\gamma/\kappa)(T_g^n)^{1/\kappa}$, where γ is the Euler-Mascheroni constant. It is a monotonic transformation of productivity location parameters measuring average technology.

Table 10: The log-deviation of CPI and PPI in response to a first-stage productivity shock: two-stage in 1998 versus three-stage in 2005

	Two-stage value chain (year 1998)		Three-stage value chain (year 2005)	
	(1)	(2)	(3)	(4)
	ΔPPI	ΔPPI/ΔCPI	ΔPPI	ΔPPI/ΔCPI
Australia	0.163	2.404	0.120	2.744
Austria	0.163	2.404	0.151	3.448
Belgium	0.163	2.404	0.156	3.563
Bulgaria	0.195	2.882	0.155	3.537
Brazil	0.163	2.415	0.136	3.113
Canada	0.163	2.404	0.131	2.999
China	0.235	3.469	0.173	3.956
Cyprus	0.163	2.405	0.130	2.958
Czech Republic	0.163	2.408	0.129	2.935
Germany	0.163	2.404	0.134	3.063
Denmark	0.163	2.404	0.130	2.960
Spain	0.163	2.404	0.125	2.862
Estonia	0.189	2.799	0.129	2.949
Finland	0.163	2.404	0.135	3.083
France	0.163	2.404	0.113	2.582
United Kingdom	0.163	2.404	0.124	2.837
Greece	0.163	2.411	0.119	2.718
Hungary	0.182	2.689	0.133	3.028
India	0.226	3.338	0.160	3.663
Indonesia	0.227	3.354	0.187	4.276
Ireland	0.163	2.404	0.135	3.077
Italy	0.163	2.404	0.125	2.847
Japan	0.163	2.404	0.129	2.955
Korea	0.163	2.415	0.129	2.943
Lithuania	0.194	2.871	0.121	2.754
Luxembourg	0.163	2.405	0.121	2.759
Latvia	0.192	2.842	0.147	3.354
Mexico	0.173	2.563	0.131	2.992
Malta	0.166	2.451	0.136	3.115
Netherlands	0.163	2.404	0.132	3.019
Poland	0.165	2.444	0.135	3.088
Portugal	0.163	2.408	0.125	2.864
Romania	0.197	2.911	0.145	3.308
Russian Federation	0.204	3.023	0.141	3.212
Slovakia	0.191	2.821	0.132	3.012
Slovenia	0.165	2.437	0.133	3.027
Sweden	0.163	2.404	0.131	2.982
Turkey	0.171	2.523	0.133	3.036
Taiwan	0.163	2.404	0.136	3.100
United States	0.163	2.404	0.132	3.012

Note: Column (1) and (2) are calibrated using WIOD 1998 data with $G = 2$. Column (3) and (4) are calibrated using WIOD 2005 data with $G = 3$. ΔCPI= 0.068 in Column (2), and ΔCPI= 0.044 in Column (4). The median of ΔPPI/ΔCPI in Column (2) is 2.408, and in Column (4) is 3.016.

Table 11: Calibration of four-stage location parameters using 2005 data

	Stage 1	Stage 2	Stage 3	Stage 4
Australia	0.548	0.322	0.420	0.426
Austria	1.010	0.234	1.098	0.690
Belgium	1.145	0.791	0.986	1.015
Bulgaria	0.858	0.666	1.021	0.963
Brazil	1.156	0.734	1.345	0.693
Canada	1.440	0.581	0.862	1.363
China	0.715	0.756	0.331	0.939
Cyprus	0.705	0.586	0.862	0.622
Czech Republic	0.809	0.807	1.151	1.141
Germany	1.157	0.607	1.055	1.034
Denmark	1.200	0.370	1.166	1.101
Spain	1.600	0.752	1.317	1.197
Estonia	1.462	0.707	1.206	1.077
Finland	0.300	0.676	0.794	1.237
France	1.451	0.663	0.485	0.933
United Kingdom	1.082	0.138	1.282	1.049
Greece	1.107	0.529	1.058	1.061
Hungary	1.594	0.740	0.749	1.069
India	1.134	0.864	0.446	0.913
Indonesia	0.121	0.004	1.262	0.961
Ireland	1.403	0.945	0.919	1.169
Italy	0.853	0.523	1.063	0.900
Japan	1.393	0.701	1.027	1.025
Korea	0.722	0.704	0.365	0.986
Lithuania	0.254	0.563	0.861	0.936
Luxembourg	1.284	0.549	0.916	1.184
Latvia	1.144	0.492	1.108	1.191
Mexico	1.520	0.688	1.003	1.273
Malta	1.105	0.705	1.149	0.985
Netherlands	1.520	0.645	1.051	0.826
Poland	1.193	0.761	0.863	1.041
Portugal	1.317	0.598	1.276	0.885
Romania	0.967	0.980	1.206	1.359
Russian Federation	1.259	0.949	1.089	1.299
Slovakia	1.209	0.632	0.962	1.200
Slovenia	1.104	0.510	1.187	0.986
Sweden	1.058	0.986	1.205	1.038
Turkey	0.780	0.499	1.186	1.371
Taiwan	0.836	0.893	0.983	0.862
United States	1.000	1.000	1.000	1.000

Note: The table reports the geometric mean of the Fréchet distribution, i.e., $exp(\gamma/\kappa)(T_g^n)^{1/\kappa}$, where γ is the Euler-Mascheroni constant. It is a monotonic transformation of productivity location parameters measuring average technology.

Table 12: The log-deviation of CPI and PPI in response to a first-stage productivity shock: two-stage in 1998 versus four-stage in 2005

	Two-stage value chain (year 1998)		Four-stage value chain (year 2005)	
	(1)	(2)	(3)	(4)
	ΔPPI	ΔPPI/ΔCPI	ΔPPI	ΔPPI/ΔCPI
Australia	0.163	2.404	0.082	2.809
Austria	0.163	2.404	0.093	3.176
Belgium	0.163	2.404	0.090	3.076
Bulgaria	0.195	2.882	0.124	4.233
Brazil	0.163	2.415	0.120	4.079
Canada	0.163	2.404	0.080	2.718
China	0.235	3.469	0.147	4.994
Cyprus	0.163	2.405	0.086	2.947
Czech Republic	0.163	2.408	0.097	3.290
Germany	0.163	2.404	0.085	2.910
Denmark	0.163	2.404	0.086	2.939
Spain	0.163	2.404	0.087	2.977
Estonia	0.189	2.799	0.110	3.741
Finland	0.163	2.404	0.080	2.728
France	0.163	2.404	0.077	2.609
United Kingdom	0.163	2.404	0.087	2.948
Greece	0.163	2.411	0.081	2.770
Hungary	0.182	2.689	0.100	3.416
India	0.226	3.338	0.151	5.153
Indonesia	0.227	3.354	0.088	2.992
Ireland	0.163	2.404	0.084	2.869
Italy	0.163	2.404	0.084	2.869
Japan	0.163	2.404	0.085	2.902
Korea	0.163	2.415	0.079	2.700
Lithuania	0.194	2.871	0.087	2.956
Luxembourg	0.163	2.405	0.077	2.619
Latvia	0.192	2.842	0.103	3.508
Mexico	0.173	2.563	0.099	3.384
Malta	0.166	2.451	0.092	3.125
Netherlands	0.163	2.404	0.095	3.232
Poland	0.165	2.444	0.098	3.354
Portugal	0.163	2.408	0.088	3.001
Romania	0.197	2.911	0.119	4.063
Russian Federation	0.204	3.023	0.122	4.170
Slovakia	0.191	2.821	0.099	3.377
Slovenia	0.165	2.437	0.088	2.984
Sweden	0.163	2.404	0.096	3.277
Turkey	0.171	2.523	0.088	2.992
Taiwan	0.163	2.404	0.099	3.366
United States	0.163	2.404	0.087	2.960

Note: Column (1) and (2) are calibrated using WIOD 1998 data with $G = 2$. Column (3) and (4) are calibrated using WIOD 2005 data with $G = 4$. ΔCPI= 0.068 in Column (2), and ΔCPI= 0.029 in Column (4). The median of ΔPPI/ΔCPI in Column (2) is 2.408, and in Column (4) is 2.997.

Table 13: The correlation between the calibrated and empirically estimated PPI elasticities

	Empirics pre-2001		Empirics post-2001		
	(1)	(2)	(3)	(4)	(5)
Data in calibration (year)	1998	1997	2005	2006	2005
	G=2	G=2	G=3	G=3	G=4
Correlation	0.441	0.498	0.388	0.328	0.186
P-value in T-test	0.9%	0.3%	1.0%	2.6%	14.3%
# Obs.	29	29	36	36	35

Note: The P-value is under the null hypothesis that the correlation between the calibrated and empirically estimated PPI elasticities is no larger than zero. In Column (3) and (4), Lithuania is treated as an outlier; in Column (5), both India and Lithuania are treated as outliers.

Appendix

A The share of internationally traded intermediate goods in total intermediate goods

Using the data from WIOD, Figure 10 presents the share of internationally traded intermediate goods in total intermediate goods. We can see a clear upward trend in USA, Japan, Germany, India, and the Euro Zone as a whole. Taking all the countries in WIOD as "Global", there is also an upward trend in the share of internationally traded intermediate goods in total intermediate goods.

B Proof for the purchasing price distribution for a specific good produced in the first stage of manufacturing sector

Let $\tilde{p}_1^n(u) = min\{p_1^{1n}(u), \ldots, p_1^{Nn}(u)\}$ and $G_1^n(p) = Pr(\tilde{p}_1^n(u) \leq p)$ be the purchasing price distribution of good u produced in stage 1, which are taken as inputs for stage 2 in country n. Then, we have

$$G_1^n(p) = Pr(\tilde{p}_1^n(u) \leq p)$$

$$= 1 - \Pi_{i=1}^N Pr(p_1^{in}(u) \geq p)$$

$$= 1 - \Pi_{i=1}^N (1 - G_1^{in}(p))$$

$$= 1 - \Pi_{i=1}^N F_1^i(\frac{w^i \tau^{in}}{p})$$

$$= 1 - exp[-\Phi_1^n p^\kappa]$$

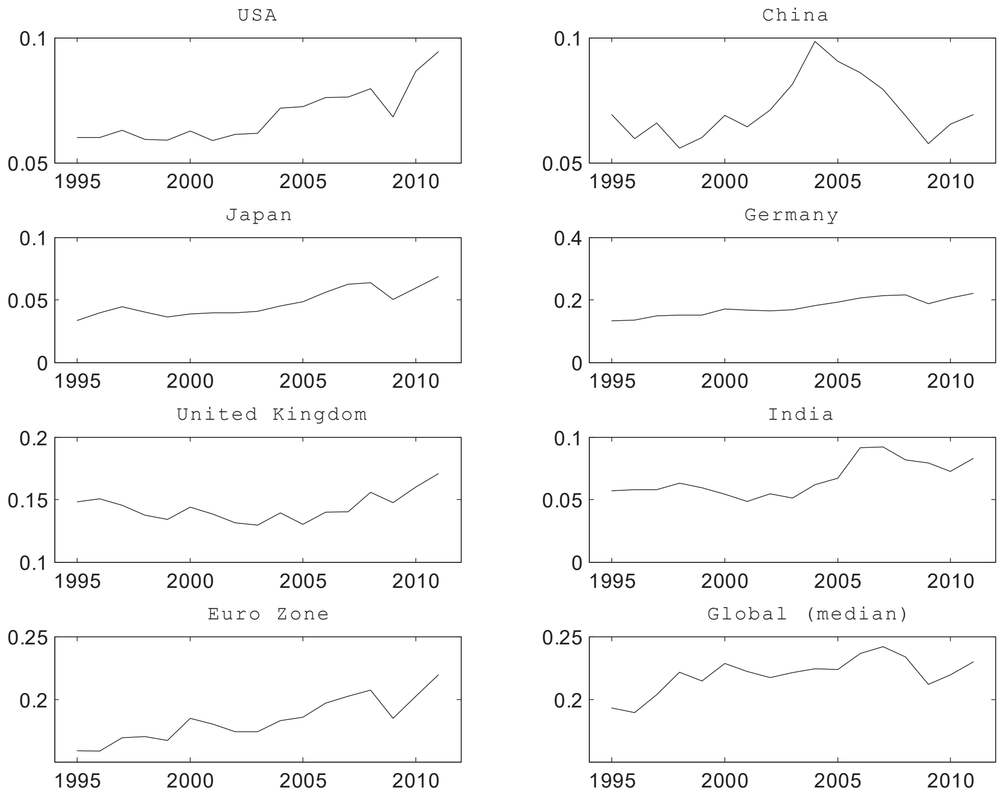

Figure 10: The share of internationally traded intermediate goods in total intermediate goods

Notes: This figure displays the share of internationally traded (i.e., imported) intermediate goods in total intermediate goods for WIOD countries. The sub-figure labeled as "global" indicates all the countries included in WIOD dataset.

C Proof for the monotonicity of PPI inflation in response to a first stage productivity shock in manufacturing sector

The response of PPI inflation to a first stage productivity shock in manufacturing sector is given by

$$|\widehat{lnPPI}/\widehat{lnT_1}| = \frac{G}{\kappa}\frac{(1-\theta)\theta^{G-1}}{1-\theta^G}$$

Denote $f(G) = \frac{1-\theta}{\kappa\theta}\frac{G\theta^G}{1-\theta^G}$, and then we have

$$\frac{\partial f}{\partial G} = \frac{1-\theta}{\kappa\theta}\frac{[\theta^G + G\theta^G ln\theta](1-\theta^G) - G\theta^G(-\theta^G ln\theta)}{(1-\theta^G)^2}$$

$$= \frac{1-\theta}{\kappa\theta}\frac{\theta^G[1-\theta^G + Gln\theta]}{(1-\theta^G)^2}$$

Denote $h(G) = 1-\theta^G + Gln\theta$. Since $\theta \in (0,1)$ and $G \geq 1$, we have $h' = (1-\theta^G)ln\theta < 0$. Note that $h(1) = 1-\theta+ln\theta$, and then $h(G) < 0$ for $\forall G \geq 1$ as long as $1-\theta+ln\theta < 0$. Since $\theta \in (0,1)$, $\partial h(1)/\partial\theta = -1+1/\theta > 0$, and $h(1) = 0$ when $\theta = 1$, it indicates that $h(1) = 1-\theta+ln\theta < 0$ for $\forall\theta \in (0,1)$.

Therefore, $\forall G \geq 1$, we have $h(G) < 0$, and $f(G)$ is strictly decreasing with respect to G. In other words, the response of PPI inflation to a first stage productivity shock in manufacturing sector, i.e., $|\widehat{lnPPI}/\widehat{lnT_1}| = \frac{G}{\kappa}\frac{(1-\theta)\theta^{G-1}}{1-\theta^G}$, is strictly decreasing with respect to G for $\forall\theta \in (0,1)$ and $\forall G \geq 1$.

D Proof for the monotonicity of $\widehat{lnPPI}/\widehat{lnCPI}$ in response to a first stage productivity shock in manufacturing sector

In response to a productivity shock in manufacturing sector, the PPI inflation and CPI inflation satisfy

$$\frac{\widehat{lnPPI}}{\widehat{lnCPI}} = \frac{G(1-\theta)}{\alpha(1-\theta^G)}$$

Note that $\theta \in (0,1)$. Denote $f = \frac{G(1-\theta)}{\alpha(1-\theta^G)}$, and then we have

$$\frac{\partial f}{\partial G} = \frac{(1-\theta)(1-\theta^G) - G(1-\theta)(-\theta^G ln\theta)}{\alpha(1-\theta^G)^2}$$

$$= \frac{(1-\theta)[1-\theta^G + G\theta^G ln\theta]}{\alpha(1-\theta^G)^2}$$

Denote $h(G) = 1 - \theta^G + G\theta^G ln\theta$, and then we have $h' = G\theta^G(ln\theta)^2 > 0$ and $h(1) = 1 - \theta + \theta ln\theta$. Also, note that

$$\frac{\partial(1-\theta+\theta ln\theta)}{\partial\theta} = ln\theta < 0$$

and $h(1) = 0$ when $\theta = 1$. Therefore, $\forall\theta \in (0,1)$, $h(1) > 0$, and $\forall G \geq 1$, $h(G) > 0$, which indicates that $\partial f/\partial G > 0$. In other words, given $\theta \in (0,1)$, $\widehat{lnPPI}/\widehat{lnCPI}$ is strictly increasing with the number of total stages, G.

E Empirical tests using other estimators

As robustness checks for the empirical tests in Section 6, we have also conducted the same regressions by the Arellano-Bond estimator and LSDV estimator. Since the Arellano-Bond estimator gives almost the same results with QML estimators, we only report the results by the LSDV estimator in this section.

Table 14: The response of CPI and PPI inflation to industrial input price

VARIABLES	(1) $\Delta lnCPI$ 1981-2001	(2) $\Delta lnPPI$ 1981-2001	(3) $\Delta lnCPI$ 2002-2014	(4) $\Delta lnPPI$ 2002-2014	(5) $\Delta lnCPI$ 2002-2014	(6) $\Delta lnPPI$ 2002-2014
$\Delta lnP_{Industrial,t}$	0.533***	0.749***	0.029***	0.142***	0.040***	0.156***
	(0.104)	(0.095)	(0.009)	(0.019)	(0.010)	(0.022)
$\Delta lnCPI_{t-1}$	0.329***		0.373***		0.415***	
	(0.056)		(0.057)		(0.062)	
$\Delta lnPPI_{t-1}$		0.171**		0.065		0.124**
		(0.075)		(0.054)		(0.054)
$Year2008$					0.047***	0.088***
					(0.004)	(0.010)
$Year2009$					-0.018***	-0.052***
					(0.004)	(0.010)
# Obs.	1,580	943	1,412	1,051	1,412	1,051
$Adj.R^2$	0.839	0.834	0.627	0.375	0.698	0.508
Ratio of Response (R)	1.405		4.897		3.900	
$R_{post,2001} - R_{pre,2001}$			3.492		2.495	
P-value, $H0: \Delta R \leq 0$			0.1%		0.3%	

Notes: This table estimates the responses of CPI and PPI inflation to changes in industrial input prices. The LSDV estimators are adopted. Variable $Year2008$ equals 1 if the observation is in the year of 2008; otherwise, 0. Variable $Year2009$ equals 1 if the observation is in the year of 2009; otherwise, 0. Variable, Ratio of Response, is the ratio of the coefficient of PPI inflation in response to industrial input price change divided by the coefficient of CPI inflation in response to industrial input price change, i.e., $\frac{\partial \Delta lnPPI_t / \partial \Delta lnP_{Industrial,t}}{\partial \Delta lnCPI_t / \partial \Delta lnP_{Industrial,t}}$. Country fixed effects have been controlled. Country-clustered robust standard errors are reported in parentheses. *** denotes $p < 0.01$, ** denotes $p < 0.05$, while * denotes $p < 0.1$.

Table 15: The response of CPI and PPI inflation to industrial input price with controlling nominal wage

VARIABLES	(1) $\Delta lnCPI$ 1981-2001	(2) $\Delta lnPPI$ 1981-2001	(3) $\Delta lnCPI$ 2002-2014	(4) $\Delta lnPPI$ 2002-2014	(5) $\Delta lnCPI$ 2002-2014	(6) $\Delta lnPPI$ 2002-2014
$\Delta lnP_{Industrial,t}$	0.408***	0.553***	0.026***	0.139***	0.039***	0.155***
	(0.123)	(0.094)	(0.009)	(0.020)	(0.010)	(0.023)
$\Delta lnCPI_{t-1}$	0.255***		0.348***		0.395***	
	(0.045)		(0.051)		(0.058)	
$\Delta lnPPI_{t-1}$		0.115		0.047		0.115**
		(0.084)		(0.048)		(0.048)
$WageDummy * \Delta lnwage_t$	0.442***	0.362***	0.185***	0.211**	0.122***	0.085
	(0.113)	(0.108)	(0.034)	(0.096)	(0.031)	(0.084)
$Year2008$					0.045***	0.087***
					(0.004)	(0.010)
$Year2009$					-0.016***	-0.051***
					(0.004)	(0.010)
# Obs.	1,580	943	1,412	1,051	1,412	1,051
$Adj.R^2$	0.880	0.856	0.639	0.385	0.704	0.509
Ratio of Response (R)	1.355		5.346		3.974	
$R_{post,2001} - R_{pre,2001}$			3.991		2.619	
P-value, $H0: \Delta R \leq 0$			1.1%		2.2%	

Notes: This table estimates the responses of CPI and PPI inflation to changes in industrial input prices. The LSDV estimators are adopted. Variable, $WageDummy * \Delta lnwage_t$, equals $\Delta lnwage_t$ if wage data are available; otherwise, 0. Variable $Year2008$ equals 1 if the observation is in the year of 2008; otherwise, 0. Variable $Year2009$ equals 1 if the observation is in the year of 2009; otherwise, 0. Variable, Ratio of Response, is the ratio of the coefficient of PPI inflation in response to industrial input price change divided by the coefficient of CPI inflation in response to industrial input price change, i.e., $\frac{\partial \Delta lnPPI_t / \partial \Delta lnP_{Industrial,t}}{\partial \Delta lnCPI_t / \partial \Delta lnP_{Industrial,t}}$. Country fixed effects have been controlled. Country-clustered robust standard errors are reported in parentheses. *** denotes $p < 0.01$, ** denotes $p < 0.05$, while * denotes $p < 0.1$.

Table 16: The response of CPI and PPI inflation to industrial input price with controlling nominal wage and price index level

	(1)	(2)	(3)	(4)	(5)	(6)
	$\Delta lnCPI$	$\Delta lnPPI$	$\Delta lnCPI$	$\Delta lnPPI$	$\Delta lnCPI$	$\Delta lnPPI$
VARIABLES	1981-2001	1981-2001	2002-2014	2002-2014	2002-2014	2002-2014
$\Delta lnP_{Industrial,t}$	0.389***	0.537***	0.025***	0.121***	0.038***	0.140***
	(0.117)	(0.095)	(0.009)	(0.016)	(0.010)	(0.020)
$\Delta lnCPI_{t-1}$	0.253***		0.347***		0.395***	
	(0.041)		(0.053)		(0.059)	
$\Delta lnPPI_{t-1}$		0.118		0.046		0.111**
		(0.083)		(0.043)		(0.043)
$lnCPI_{t-1}$	-0.017***		-0.005		-0.002	
	(0.005)		(0.008)		(0.008)	
$lnPPI_{t-1}$		-0.010*		-0.053***		-0.044***
		(0.005)		(0.013)		(0.012)
$WageDummy * \Delta lnwage_t$	0.422***	0.353***	0.179***	0.191**	0.120***	0.071
	(0.114)	(0.107)	(0.035)	(0.077)	(0.032)	(0.067)
$Year2008$					0.045***	0.085***
					(0.004)	(0.009)
$Year2009$					-0.016***	-0.048***
					(0.004)	(0.010)
Observations	1,580	943	1,412	1,051	1,412	1,051
R-squared	0.886	0.858	0.640	0.410	0.704	0.527
Ratio of Response (R)	1.380		4.840		3.684	
$R_{post,2001} - R_{pre,2001}$			3.460		2.304	
P-value, $H0: \Delta R \leq 0$			1.3%		2.7%	

Notes: This table estimates the responses of CPI and PPI inflation to changes in industrial input prices. The LSDV estimators are adopted. Variable, $WageDummy * \Delta lnwage_t$, equals $\Delta lnwage_t$ if wage data are available; otherwise, 0. Variable $Year2008$ equals 1 if the observation is in the year of 2008; otherwise, 0. Variable $Year2009$ equals 1 if the observation is in the year of 2009; otherwise, 0. Variable, Ratio of Response, is the ratio of the coefficient of PPI inflation in response to industrial input price change divided by the coefficient of CPI inflation in response to industrial input price change, i.e., $\frac{\partial \Delta lnPPI_t / \partial \Delta lnP_{Industrial,t}}{\partial \Delta lnCPI_t / \partial \Delta lnP_{Industrial,t}}$. Country fixed effects have been controlled. Country-clustered robust standard errors are reported in parentheses. *** denotes $p < 0.01$, ** denotes $p < 0.05$, while * denotes $p < 0.1$.

Table 17: The response of CPI and PPI inflation to industrial input price with exchange rate

VARIABLES	(1) $\Delta lnCPI$ 1981-2001	(2) $\Delta lnPPI$ 1981-2001	(3) $\Delta lnCPI$ 2002-2014	(4) $\Delta lnPPI$ 2002-2014	(5) $\Delta lnCPI$ 2002-2014	(6) $\Delta lnPPI$ 2002-2014
$\Delta lnP_{Industrial,t}$ (USD)	0.061***	0.214***	0.021***	0.135***	0.025***	0.135***
	(0.021)	(0.053)	(0.007)	(0.015)	(0.007)	(0.015)
$\Delta lnCPI_{t-1}$	0.236***		0.340***		0.395***	
	(0.046)		(0.049)		(0.055)	
$\Delta lnPPI_{t-1}$		0.095		0.043		0.106**
		(0.073)		(0.046)		(0.046)
$\Delta lnExchangeRate_t$	0.488***	0.684***	0.062**	0.156***	0.096***	0.218***
	(0.133)	(0.091)	(0.031)	(0.059)	(0.034)	(0.064)
$WageDummy * \Delta lnwage_t$	0.386***	0.257**	0.197***	0.219**	0.134***	0.108
	(0.112)	(0.102)	(0.033)	(0.088)	(0.029)	(0.075)
$Year2008$					0.044***	0.085***
					(0.004)	(0.010)
$Year2009$					-0.024***	-0.061***
					(0.004)	(0.010)
# Obs.	1,580	943	1,412	1,051	1,412	1,051
$Adj.R^2$	0.899	0.871	0.643	0.385	0.715	0.517
Ratio of Response (R)	3.508		6.429		5.400	
$R_{post,2001} - R_{pre,2001}$			2.921		1.892	
P-value, $H0: \Delta R \leq 0$			7.7%		13.5%	

Notes: This table estimates the responses of CPI and PPI inflation to changes in industrial input prices. The LSDV estimators are adopted. Variable, $WageDummy * \Delta lnwage_t$, equals $\Delta lnwage_t$ if wage data are available; otherwise, 0. Variable $Year2008$ equals 1 if the observation is in the year of 2008; otherwise, 0. Variable $Year2009$ equals 1 if the observation is in the year of 2009; otherwise, 0. Variable, Ratio of Response, is the ratio of the coefficient of PPI inflation in response to industrial input price change divided by the coefficient of CPI inflation in response to industrial input price change, i.e., $\frac{\partial \Delta lnPPI_t / \partial \Delta lnP_{Industrial,t}}{\partial \Delta lnCPI_t / \partial \Delta lnP_{Industrial,t}}$. Country fixed effects have been controlled. Country-clustered robust standard errors are reported in parentheses. *** denotes $p < 0.01$, ** denotes $p < 0.05$, while * denotes $p < 0.1$.

Table 18: The response of CPI and PPI inflation to commodity price

VARIABLES	(1) $\Delta lnCPI$ 1993-2001	(2) $\Delta lnPPI$ 1993-2001	(3) $\Delta lnCPI$ 2002-2014	(4) $\Delta lnPPI$ 2002-2014	(5) $\Delta lnCPI$ 2002-2014	(6) $\Delta lnPPI$ 2002-2014
$\Delta lnP_{Commodity,t}$	0.439***	0.772***	0.086***	0.246***	0.070***	0.232***
	(0.134)	(0.133)	(0.010)	(0.029)	(0.016)	(0.036)
$\Delta lnCPI_{t-1}$	0.350***		0.480***		0.464***	
	(0.050)		(0.044)		(0.049)	
$\Delta lnPPI_{t-1}$		0.161*		0.092*		0.079
		(0.096)		(0.050)		(0.051)
$Year2008$					0.032***	0.037***
					(0.004)	(0.007)
$Year2009$					-0.002	0.002
					(0.007)	(0.014)
Observations	792	505	1,386	1,025	1,386	1,025
R-squared	0.799	0.763	0.686	0.539	0.712	0.556
Ratio of Response (R)	1.759		2.860		3.314	
$R_{post,2001} - R_{pre,2001}$			1.101		1.555	
P-value, $H0: \Delta R \leq 0$			7.9%		6.8%	

Notes: This table estimates the responses of CPI and PPI inflation to changes in commodity prices. The LSDV estimators are adopted. Variable $Year2008$ equals 1 if the observation is in the year of 2008; otherwise, 0. Variable $Year2009$ equals 1 if the observation is in the year of 2009; otherwise, 0. Variable, Ratio of Response, is the ratio of the coefficient of PPI inflation in response to primary commodity price change divided by the coefficient of CPI inflation in response to primary commodity price change, i.e., $\frac{\partial \Delta lnPPI_t / \partial \Delta lnP_{Commodity,t}}{\partial \Delta lnCPI_t / \partial \Delta lnP_{Commodity,t}}$. Country fixed effects have been controlled. Country-clustered robust standard errors are reported in parentheses. *** denotes $p < 0.01$, ** denotes $p < 0.05$, while * denotes $p < 0.1$.

Table 19: The response of CPI and PPI inflation to commodity price with controlling nominal wage and price index level

VARIABLES	(1) $\Delta lnCPI$ 1993-2001	(2) $\Delta lnPPI$ 1993-2001	(3) $\Delta lnCPI$ 2002-2014	(4) $\Delta lnPPI$ 2002-2014	(5) $\Delta lnCPI$ 2002-2014	(6) $\Delta lnPPI$ 2002-2014
$\Delta lnP_{Commodity,t}$	0.262***	0.562***	0.083***	0.231***	0.069***	0.216***
	(0.100)	(0.111)	(0.010)	(0.027)	(0.015)	(0.033)
$\Delta lnCPI_{t-1}$	0.239***		0.459***		0.443***	
	(0.046)		(0.042)		(0.048)	
$\Delta lnPPI_{t-1}$		0.117*		0.081*		0.069
		(0.068)		(0.043)		(0.043)
$lnCPI_{t-1}$	-0.085***		0.002		0.000	
	(0.024)		(0.006)		(0.007)	
$lnPPI_{t-1}$		-0.097***		-0.028**		-0.031***
		(0.027)		(0.011)		(0.011)
$WageDummy * \Delta lnwage_t$	0.427***	0.228**	0.126***	0.108	0.108***	0.091
	(0.121)	(0.107)	(0.032)	(0.070)	(0.030)	(0.069)
$Year2008$					0.031***	0.039***
					(0.004)	(0.007)
$Year2009$					-0.000	0.002
					(0.006)	(0.013)
Observations	792	505	1,386	1,025	1,386	1,025
R-squared	0.882	0.801	0.691	0.549	0.717	0.567
Ratio of Response (R)	2.145		2.783		3.130	
$R_{post,2001} - R_{pre,2001}$			0.638		0.985	
P-value, $H0: \Delta R \leq 0$			24.4%		19.9%	

Notes: This table estimates the responses of CPI and PPI inflation to changes in commodity prices. The LSDV estimators are adopted. Variable, $WageDummy * \Delta lnwage_t$, equals $\Delta lnwage_t$ if wage data are available; otherwise, 0. Variable $Year2008$ equals 1 if the observation is in the year of 2008; otherwise, 0. Variable $Year2009$ equals 1 if the observation is in the year of 2009; otherwise, 0. Variable, Ratio of Response, is the ratio of the coefficient of PPI inflation in response to primary commodity price change divided by the coefficient of CPI inflation in response to primary commodity price change, i.e., $\frac{\partial \Delta lnPPI_t / \partial \Delta lnP_{Commodity,t}}{\partial \Delta lnCPI_t / \partial \Delta lnP_{Commodity,t}}$. Country fixed effects have been controlled. Country-clustered robust standard errors are reported in parentheses. *** denotes $p < 0.01$, ** denotes $p < 0.05$, while * denotes $p < 0.1$.