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# On the Wedge Between the PPI and CPI Inflation Indicators

by Shang-Jin Wei[1] and Yinxi Xie[2]

[1]Columbia Business School, Columbia University
shangjin.wei@columbia.edu

[2]Canadian Economic Analysis Department
Bank of Canada, Ottawa, Ontario K1A 0G9
YinxiXie@bankofcanada.ca



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# Abstract

While two strands of the literature suggest that PPI inflation, in addition to or instead of CPI inflation, should be a targeting variable in a monetary policy rule, the distinction between the two is only important when they do not co-move strongly. Our first contribution is to document that their correlation has indeed fallen substantially since the start of this century. Our second contribution is to propose a model to understand this divergence based on expanding global supply chains. Our theory produces additional predictions that are also confirmed in the data. As such changes are structural rather than temporary, the standard monetary policy rule that does not target the PPI inflation may have become increasingly problematic.



*Topics: Inflation and prices; Inflation targets; International topics; Monetary policy*

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# 1 Introduction

Inflation is a central variable of interest to macroeconomics. While consumer price index (CPI) inflation measures changes in the prices of goods and services that households purchase, producer price index (PPI) inflation captures changes in the prices of goods made by domestic producers. While a number of papers have suggested that PPI inflation should be directly included in a central bank's monetary policy rule, its necessity depends in part on whether PPI and CPI co-move strongly. This paper documents a dramatic fall in the correlation between the two inflation measures since the beginning of this century. This change happens in both the cross-country correlations and the time-series correlations.

We also investigate the role of global supply chains in this development, and propose a model that explains the increased wedge between the two inflation indicators through a lengthening of global supply chains. We derive additional predictions from the model, including differential responses between PPI and CPI to common global commodity price shocks, and some cross-country differences as a function of their trade costs and productivity, and test these in the data. In our theory, the declining correlation is not a result of increased measurement errors in the PPI index. Our theory and empirics suggest that the changed relationship between PPI and CPI inflation and its implication for the design of monetary policy are unlikely to be temporary.

While our theory features no sticky prices (for simplicity), understanding the causes of the wedge has important implications for the design of monetary policies. While almost all central banks target only CPI inflation at this moment, the literature has pointed to two reasons why PPI inflation should instead be the target (not just a forecasting variable for CPI inflation). First, Galí and Monacelli (2005), De Paoli (2009), and Lombardo and Ravenna (2014) show that in an open economy, in which PPI differs from CPI by including prices of domestic products only and excluding those of imported products, central banks should focus on the inflation of domestic products, which PPI inflation captures better.[1] Second, with multi-stage production, Huang and Liu (2005) and Wei and Xie (2020) show that, for a closed economy and an open economy, respectively, it is also better to include PPI inflation rather than CPI inflation in the monetary policy rule. Wei and Xie (2020) and Rubbo (2020) further investigate different ways to incorporate producer price inflation in an optimal monetary policy. Based on this literature, the findings of the current paper implies that a monetary rule that treats PPI inflation merely as a predictor of CPI inflation is no longer appropriate. The previous literature that advocates putting weights directly on PPI inflation in the monetary policy rule deserves a new look by central banks.

If PPI inflation and CPI inflation co-move strongly in the data, the distinction between the two inflation targets in theory would be unimportant in practice. Do PPI and CPI co-move? Our first contribution is to present evidence of an apparent structural change: the two inflation indicators did co-move strongly in the 1980s and 1990s (with a correlation consistently above 90%), so the practice of targeting only CPI inflation was nearly harmless. This might be why central banks do not typically look beyond CPI inflation, or if they do, they typically use PPI inflation only as a forecasting variable for CPI inflation, rather than as a stand-alone targeting variable. However, we also show a dramatic decline in the correlation between the two indices (to somewhere around 70%) since the start of this century. Indeed, in some countries, such as the United States, the Euro zone, China, Republic of Korea, India, Singapore, Thailand, Philippines, and Malaysia, the two inflation indicators even moved in opposite directions in the recent past: While CPI inflation rates were moderately positive, PPI inflation rates were negative. (In 2021, the divergence takes a

[1] Corsetti, Dedola, and Leduc (2010) provide a useful survey of the existing literature on monetary policy in an open economy. Important relevant references include Benigno and Benigno (2003) and De Gregorio (2012).

different form. While US CPI inflation is about 6%, PPI inflation has reached 50%.) The divergence appears in both time series of the two inflation indices and the cross-country correlations. To our knowledge, this is the first paper that documents the emergence of this significant wedge between the two inflation measures and proposes a theory based on supply chain development.

Is the divergence between the two inflation indices a temporary aberration so that relatively little is lost if central banks continue to ignore PPI, or is it something more structural? If it is more structural, the literature suggests a policy that targets only CPI will be associated with a higher welfare cost. To answer this question requires an understanding of why PPI and CPI have diverged in the 21st century. Yet, we are not aware of either theoretical or empirical papers that study the causes of the divergence. As the importance of supply chains (or an input-output structure) is a key rationale in theory for incorporating PPI inflation in the monetary policy rule,[2] we study in this paper whether supply chains also play an important role as a channel in the recent divergence between the two inflation indicators. Indeed, the intermediate inputs as a share of global gross output have not only been rising over time, but the pace of the increase appears to have accelerated since the start of this century. This would, in principle, not only open up a wedge between the PPI and CPI baskets, but the wedge may also have grown structurally bigger in recent years.

The rising importance of global supply chains likely comes from a confluence of two forces. First, advancement in digital technology had matured enough around the turn of the century to generate systematic attempts by firms in various industries to codify as much of the production processes as possible, and to outsource those codifiable tasks from high-wage to low-wage countries (e.g., Fort, 2017). Second, the rise of Central and Eastern Europe as a production backyard for Western Europe since the late 1990s and China's accession to the World Trade Organization in 2001 have provided the world with a set of eager recipients of a relocation of global production capacities. China in particular has come out of decades of economic isolation to become a dominant "factory of the world."[3] Trade liberalizations in Mexico and many countries in South America and Southeast Asia also contributed to this wave of outsourcing and offshoring activities.

The upshot of these two forces is a pick-up in the share of intermediate goods in many countries' imports and exports.[4] The average production length for the world as a whole – measured by the average number of times that value added passes through different country sectors before it is embedded in the final product – experienced an acceleration after 2001 as reported by Wang et al. (2017). The results that we will report later in the paper also indicate that the average number of production stages in the world economy has increased from about two at the end of the last century to about four now.

When the number of production stages increases, our model shows that the wedge in the composition of the baskets between CPI and PPI also increases, since the only common component between the two baskets is domestically produced final goods. The increased wedge reduces the correlation between the two price indices both between the time series of the two inflation measures and across countries. Note that the paper does not model why the production length has increased since 2001. Instead, we take it as given and study what it means for the relationship between PPI and CPI inflation measures in theory, and perform empirical tests of its implications.

[2] See Huang and Liu (2005), Wei and Xie (2020), La'O and Tahbaz-Salehi (2020), and Rubbo (2020). Supply chains can also alter the transmission of monetary policy shocks (see Pasten, Schoenle, and Weber, 2019 and 2020; and Ozdagli and Weber, 2020).

[3] The growth rate of its exports from 2000 to 2007 was twice as high as its already high GDP growth during that period (see Feenstra and Wei, 2010, for a comprehensive examination of the phenomenal emergence of China as a trading superpower, including the outsized role of multinational firms in China's imports and exports). Additionally, China's exports of intermediate goods have been growing faster than its exports of final goods (e.g., Wang et al., 2017).

[4] For additional evidence, see Hummels, Ishii, and Yi (2001), Koopman, Wang, and Wei (2014), and Johnson and Noguera (2017).

To capture the essence of global value chains, our model features many countries and multiple stages of production (for the tradable manufacturing sector) in a static and real environment, which abstracts from potential nominal factors so as to emphasize the real channel of global supply chains in affecting price indices. At any given stage of production, manufacturing firms in a given country can choose to buy intermediate inputs from any country in the world. The ultimate decision of where and how much to buy is endogenously made, based on a comparison of costs inclusive of trade costs and factory-gate prices, which in turn informs country-production stage-specific productivity shocks.

This model generates the prediction that, as the number of production stages increases, the correlation between PPI and CPI inflation falls following any given stage-specific productivity shock. Importantly, it generates additional predictions that can be tested in the data. In particular, as the production length increases, both CPI and PPI inflation become less sensitive to global commodity prices, and the decline is greater for CPI inflation.

Empirically, we investigate how CPI and PPI in the actual data react to the global industrial input prices (as reported by the IMF) as a proxy to an early-stage productivity shock. Since world production exhibits a pronounced increase in the total production length around the turn of the century (Wang et al., 2017), we separate the data into two periods – before and after 2001 – and study whether and how the impulse responses of PPI and CPI to an input price shock have changed respectively in the two periods. To focus on the real feature of price indices as predicted by the model, we control for country-specific nominal labor costs. Consistent with the theory, we find that both CPI inflation and PPI inflation have become less responsive to a change in industrial input prices after 2001, and the decline in percentage term is significantly greater for CPI than for PPI. As a robustness check, we also study the PPI and CPI responses to commodity price shocks and find similar patterns. In other words, the data confirms the model's predictions beyond the correlation between CPI and PPI.

We also consider some alternative (but informal) explanations for the falling correlation between the two inflation indicators. First, an increase in the share of services in the consumption basket could cause a decline in the correlation between the two inflation measures. Our theoretical model has incorporated the effects of changes in service share in final demand on the correlation between CPI and PPI inflation and has confirmed this intuition. However, while the service sector share did increase in many economies in the data, there was no visible acceleration around the turn of the century. Hence, this explanation is unlikely to have played an important role in the PPI/CPI pattern that we study. A second alternative hypothesis is that trade globalization may have reduced the markups on manufacturing goods more than on services. If this is the case, it could produce a decline in the correlation between the two inflation measures too. However, recent work by Autor et al. (2020) and De Loecker and Eeckhout (2020) suggest that globalization may have led to an increase rather than a decrease in the markup in production.[5] This takes away a key ingredient of the alternative hypothesis. Moreover, the results of our empirical exercises appear to contradict another implication of this alternative hypothesis: globalization makes PPI and CPI more responsive to a change in global commodity prices or global industrial input prices. Thus, the second alternative hypothesis is also unlikely to be an empirically important explanation. Having said all this, we should note that our story and the alternative explanations are not mutually exclusive. Since the longer production chain hypothesis has not been explored in the literature, we focus on developing this story and validating its main empirical implications in this paper, rather than excluding alternative explanations.

[5] De Loecker and Eeckhout (2020) also suggest that the growth rate of markup in most countries and regions decreases after 2000, though still being positive.

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 similar results. However, the manner through which a lengthening of supply chains takes place is via more international outsourcing and more international trade in intermediate goods.[6] Since different countries face different trade costs and different productivity levels, the inflation response to a given global shock can vary by country. As a more ambitious exercise, for the countries covered in the World Input-Output Database (WIOD), we calibrate the theoretical responses of both CPI and PPI at the country level to a first-stage productivity shock. These model-generated responses vary by country. Separately, for each country, we use actual data on the inflation series and global industrial input price series to estimate the elasticities of the CPI and PPI inflation with respect to changes in the industrial input prices, respectively. We then investigate if the model-implied and empirically estimated elasticities are positively related to each other. If our model is useful in understanding the behavior of the PPI/CPI index, we should be able to reject the null of a zero correlation in favor of the alternative of a positive correlation.

It is worth stressing that the model-implied elasticities are calibrated only using our model and the WIOD data, and the construction of WIOD does not use PPI/CPI data. On the other hand, the empirical elasticities are estimated by regressing the PPI/CPI inflation on changes in global industrial input price index (and other control variables), without using either the model or the WIOD. For these reasons, this exercise is an ambitious one. We find that we can indeed reject the null of a zero correlation between the model-implied and empirically estimated elasticities at the 5% level or better in favor of the alternative of a positive correlation.

To summarize, the main contribution of this paper is to highlight a significant divergence between CPI and PPI inflation since the start of the new century. This has two implications for the monetary economics literature. First, by documenting a breakdown in the correlation between PPI and CPI inflation, it adds gravitas to the literature that distinguishes PPI and CPI in monetary policy rules. In particular, while the distinction was not important in the last century when the two inflation indices co-moved strongly, it has become more important today. When PPI inflation is negative and CPI inflation is (modestly) positive, as happened in the United States and a number of other countries in recent years, the optimal monetary policy as proposed in these studies will be more expansionary under the PPI target than under the CPI target, and the standard monetary policy rule that targets only CPI inflation becomes more inferior (in terms of welfare loss) relative to a rule that targets PPI inflation. Second, the paper provides a structural explanation for the changing correlation between the two inflation indices – a rise in the number of production stages or a lengthening of world production since the start of this century. This structural explanation suggests that the change could be permanent.

This paper also contributes to the literature on the measurement and welfare implications of global value chains (e.g., Hummels, Ishii, and Yi, 2001; Yi, 2003 and 2010; Ramondo and Rodríguez-Clare, 2013; Koopman, Wang, and Wei, 2014; Alfaro et al., 2019; Johnson and Noguera, 2017; Antràs and de Gortari, 2020).[7] It should be pointed out that none of these papers studies the implications of global value chains for understanding the two inflation indices.

This paper is also related to the literature on international transmissions of shocks (e.g., Huang and Liu, 2007; Boivin and Giannoni, 2008; Monacelli and Sala, 2009; Auer, Borio, and Filardo, 2017; Auer,

[6] In Appendix Figure $A.3$ of Appendix $A$, we present evidence of an upward trend in the share of internationally traded (i.e., imported) intermediate goods in total intermediate goods for major countries.

[7] More examples include Antràs and Chor (2013), Costinot, Wang, and Vogel (2013), Timmer et al. (2014), and Johnson and Moxnes (2019).

Levchenko, and Sauré, 2019).[8] Auer, Borio, and Filardo (2017) and Auer, Levchenko, and Sauré (2019) suggest international input-output linkages as a channel for foreign demand shocks to influence domestic inflation. We add to this literature by documenting the smaller co-movement between the PPI and CPI inflation indices across countries and show that the co-movement depends on the length of global supply chains.

In terms of our methodology, the cross-country purchase of inputs in any given stage follows an Eaton-Kortum (2002) model. Our vertical linkage is an application of Caliendo and Parro (2015) (which does not deal with either inflation indicators or monetary policy). Within the macroeconomics literature, Huang and Liu (2001 and 2005) and Wei and Xie (2020) study the effects of vertical production chains for either the design of monetary policy or the persistence of macro variables. These papers do not feature input sourcing from multiple countries and do not use an Eaton-Kortum setup. None of these papers investigates the effect of lengthening production chains on the PPI and CPI relationship.

In a model featuring both multiple stages and multiple countries of production, achieving tractability is non-trivial. One generally needs to impose some strong structures to simplify the problem. While Antràs and de Gortari (2020) have proposed some simplifications to achieve model tractability,[9] we propose a different way. In particular, the input into the production of a stage $g$ is assumed to be an aggregate of all goods produced in the proceeding stage $(g-1)$. This modeling assumption can presumably be useful in other research that needs to model multi-stage multi-country productions.

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 the start of the current century; Section 3 introduces the settings of the model; Section 4 solves the general equilibrium and formally defines CPI and PPI indices; Section 5 discusses the response of CPI and PPI inflation to productivity shocks and trade-cost shocks, and in particular, Section 5.2 further derives an explicit solution to the responses of CPI and PPI inflation to different types 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 present formal evidence of a sizable decline in the correlation between the PPI and CPI inflation indicators since the start of century.[10] We will examine both the correlation between the two inflation indices across countries and the correlation between the time-series of PPI and CPI for a given country. Both exhibit a decline from the pre-2001 period to the post-2001 period. Our subsequent model will imply both patterns as well.

The top panel of Figure 1 presents the correlations between annual CPI and PPI inflation rates across countries - one correlation coefficient per year - from 1970 to 2015. Each blue point in the figure is a

[8] More examples include Ambler, Cardia, and Zimmermann (2002), Kose, Prasad, and Terrones (2003), Mumtaz and Surico (2012), and Jin and Li (2018).

[9] The three alternative assumptions in Antràs and de Gortari (2020) include: the existence of a lead firm for each final good that solves one optimization problem for all firms in different stages of production, any producer knows its own and direct supplier's productivity but only the distribution (Fréchet) of more upstream producers, or a combination of some special distributional assumptions for buyer-seller stage-specific productivity and the number of sellers per buyer so that the buyer's output price in each stage follows a Fréchet distribution.

[10] The data for CPI and PPI are collected from the IMF and national sources. In some countries with multiple CPI indices available, we choose the headline CPI index, which is the one with the most broad coverage of consumer basket, so as to be consistent with the CPI definition at the IMF and to facilitate cross-country comparison.

correlation in a given year across all countries with available data. It is clear that the correlation was very high (above 90%) in the last century. That is, countries with a high CPI inflation were also those with a high PPI inflation, and vice versa. However, a visible fall in the correlation occurred around the turn of the century. That is, we are now more likely to encounter the scenario of having a high CPI inflation and a low PPI inflation (or vice versa). As discussed in the introduction, the two inflation indicators can even take on opposite signs.

If one is worried about noises in the annual data, one can look at correlations between smoothed CPI and PPI inflation. The middle panel presents the correlation over (rolling) 5-year intervals. The bottom panel gives the correlation over 10-year intervals. We can see clearly that the two inflation indices move together very strongly in the last century, but then a divergence occurs in this century.

Because the country coverage tends to increase over time, it may be useful to check if the pattern holds for a constant sample of countries. While CPI is available for almost all countries throughout the sample, the country coverage of PPI data grows progressively over time. One might wonder if the decline in the average correlation across countries is due to lower correlations from newly added countries. 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 this set of countries as well: namely, the correlations were very high in the previous century 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 got rid of very high inflation by the 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 also include the initial level of inflation as a control variable. We will see that all the results are robust.

We now check whether and how the correlation between the time series of the two inflation indicators within a country has changed since the turn of the century. To do this, the data for a given country is divided into two sub-periods, 1996-2001 and 2002-2007. (We stop at 2007 as we do not want the Global Financial Crisis period to contaminate the calculations.) For each country in each sub-period, we compute a correlation between the CPI and PPI inflation. We will examine the average pattern across countries.

In Figure 2, we plot two cumulative distributions of the time-series correlation across all countries for the 1996-2001 and 2001-2007 periods, respectively. A common set of countries is used for both time periods. It is obvious that the correlations tend to be higher before 2001 than after 2001. Formally, 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-2001 curve. A more direct Dunn's test reveals that the pre-2001 distribution curve stochastically dominates the post-2002 curve at the 1% level.[11] In other words, there has been a statistically significant decline in the correlation between the two inflation measures from the pre-2001 period to more recent years.

To ensure that the different income levels of the countries do not affect the results, we have also looked at developed and developing countries separately. Figure 3 presents two box-whisker plots of the correlation between PPI and CPI inflation for high-income countries for the two periods, respectively. For the 1996-2001 period, the mean and median values of the correlation are 0.54 and 0.66, respectively. In comparison, for the post-2001 period, they are 0.33 and 0.41, respectively. In other words, there is a downward shift in the distribution of the correlation from the 1996-2001 period to the 2002-2007 period.

[11] 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.

Similarly, Figure 4 presents two box-whisker plots for the developing country group in the two time periods, respectively. For the pre-2001 period, the mean and median values of the PPI-CPI correlation are 0.67 and 0.78, respectively. For the post-2001 period, they have declined to 0.51 and 0.60, respectively. In other words, the correlation between the two inflation indices becomes weaker since the turn of the century for both developed and developing countries.[12]

To summarize, PPI and CPI inflation indicators used to exhibit a strong co-movement both across countries and over time. This high correlation renders any theoretical distinction between monetary policy rules that target different inflation indicators much less important in practice. However, as the two inflation indicators have become less correlated in the new century, the form of the optimal monetary policy may need to be reconsidered. Although this paper focuses on understanding the divergences between PPI and CPI inflation, it clearly has relevance for monetary economics: if the divergence between the two inflation indicators is not transitory, the standard practice by central banks of only targeting CPI inflation, but not PPI inflation, may have become structurally inferior (e.g., Galí and Monacelli, 2005; Huang and Liu, 2005; Wei and Xie, 2020).[13]

Have the two inflation indicators become less correlated when the supply chains become longer? One intuitive way to measure the length of supply chains is the ratio of gross output to value added. As the number of production stages increases, more intermediate goods are produced, and gross output should increase faster than value added. As supply chains are often global, it is informative to compare global gross output to global value added as a gauge of the average length of supply chains in the world economy. The Eora global supply chain database reports both gross output and value added by country and year.[14] There are 43 countries in total for which we can obtain data on both gross output and value added, in addition to both PPI and CPI inflation indices, from 1990 to 2014.

We summarize the information in Figure 5 (where the red vertical line is the year 2002). The blue dots represent the correlation between CPI and PPI inflation across all sample countries in period $t$, which are consistent with the pattern in panel (a) of Figure 1 (for a constant sample of countries since 1990). The red dots represent the ratio of global gross output to global value added in period $t-1$.[15] The ratio of gross output to value added is lagged by one year to account for the time it takes to move goods from one intermediate stage to subsequent stages of production. For example, the production of airplanes and cars may involve parts and components made a year ago. So the PPI and CPI inflation may respond to the production structure with a time lag. We can alternatively lag the ratio of gross output to value added by 2 or 3 years without fundamentally changing the main message from the graph.

To reduce noises in annual data, we have taken 5-year moving averages for both data series. The most striking feature of the figure is a sharp decline in the (cross-country) correlation between CPI and PPI

[12] In fact, we also notice a rebound in both the cross-country and time-series correlations between the CPI and PPI inflation right after the Great Recession and in recent years. The former rebound may be due to the global financial crisis that could dominate the co-movement of CPI and PPI. The rebound in recent years is consistent with our explanation via the length of global supply chains. Our story predicts that the shortening of global supply chain will lead to an increase in the (cross-country and time-series) correlation between the two inflation measures. The OECD, among others, documents a decline in fragmentation of production across borders in recent years (see the report "COVID-19 and global value chains: Policy options to build more resilient production networks").

[13] While many central banks take PPI inflation into account in making forecasts of CPI inflation, this is not the same thing as incorporating the PPI inflation into the monetary policy rule. Indeed, the theory and the evidence in this paper suggest that the PPI inflation indicator has become a structurally poorer predictor of the CPI inflation, but this is precisely why the PPI inflation should be incorporated directly into the monetary policy rule.

[14] The Eora global supply chain database is available at www.worldmrio.com. It covers 190 countries of varying length. We can obtain PPI and CPI data since 1990 for only 43 countries. Lenzen et al. (2013) provide an explanation of the Eora data.

[15] We calculate the ratio of global gross output to global value added in each year by aggregating all the countries in the sample together.

inflation since 2002, and a near simultaneous rise in the ratio of global gross output to global value added. The aim of the paper is to argue that this is not a coincidence but a natural outcome of an expansion of global value chains.

When we regress the correlation between PPI and CPI inflation on the ratio of global gross output to global value added, an intercept, and a time trend, the slope coefficient on the ratio of gross output to value added is $-1.19$ and statistically significant at the 5% level.[16] In Figure 8, we plot the correlation between CPI and PPI inflation against the ratio of gross output to value added. We can see a clear negative relationship: when the global supply chain grows, the two inflation indicators become less correlated across countries.

In the rest of the paper, we will construct a model in which lengthening supply chains can cause a decline in the PPI-CPI correlation in both the cross-country sense and the time-series sense. We will also derive additional predictions from this model. For example, what does such a model mean for the responses of PPI and CPI inflation to global commodity price shocks? Our model predicts that both will become less sensitive to commodity price shocks, and the decline in the sensitivity will be greater for the CPI inflation. As an additional way to check if the model is a sensible description of the world, we will conduct statistical tests for these additional implications.

# 3 The model setting

Consider a model with $N$ countries, denoted by $n = 1, 2, \cdots, N$, and two sectors, with manufacturing sector denoted by $m$ and service sector denoted by $s$. 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 (as well as domestically). The service sector features a single-stage production, and the output is non-tradable internationally.[17] Figure 7 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 across countries, sectors, and stages.

Given the complexity in modeling supply chains both across stages of production and across countries, we develop our story in a model that does not feature sticky prices or monetary policies. Both Huang and Liu (2005) and Wei and Xie (2020) feature sticky prices and monetary policies in a simplified supply chain model. They do not discuss how the relationship between PPI and CPI may change with an increased production length.

## 3.1 The manufacturing sector

Manufacturing production requires $G$ stages, with each stage following a standard Eaton-Kortum framework. In the first stage, the production function for good $u$ in country $n$ is given by

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

[16] We exclude 2008-2009 from the regression sample so that our inference would not be unduly affected by the Great Recession.

[17] In the real world, "service" sectors have a broad meaning and could contribute to the manufacturing process. Here we define the service sector conceptually in the model for only those activities that do not participate in the manufacturing process and whose outputs directly serve to the final demand, e.g., education services. This setup is also consistent with the literature in modeling global supply chains (e.g., Johnson and Moxnes, 2019).

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

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

where $\Theta = [(1-\theta^n)^{1-\theta^n}(\theta^n)^{\theta^n}]^{-1}$ 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 snake and 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.

Firms in each stage of manufacturing production could purchase inputs from any country, but subject to a bilateral iceberg trade cost $\tau^{in}$ 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

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

where $T_g^n$ is the location parameter, $\kappa$ 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

$$Pr(Z_s^n(u) \leq z) = F_s^n(z) = e^{-T_s^n z^{-\kappa}},$$

where $T_s^n$ is the location parameter and $\kappa$ is the shape parameter.[18]

### 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 composite manufacturing good and a composite service good, denoted as $Q^n$ and $S^n$, respectively, by a constant elasticity of substitution (CES) transformation. That is,

$$Q^n = \exp(\int_0^1 \ln(\tilde{q}_G^n(u))du), \quad S^n = \exp(\int_0^1 \ln(s^n(u))du),$$

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

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

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

The aggregation process described above follows 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 (with a unity elasticity) 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. Following Johnson and Moxnes (2019), the trade balance $TB^n$ in country $n$ is assumed to be exogenous, as a nominal transfer necessary to equate income and expenditure in country $n$ (i.e., $w^n L^n = P_F^n F^n + TB^n$).

# 4 General equilibrium

### 4.1 The CPI definition

The CPI is defined as the weighted average of the prices faced by households, including the prices of final goods from both the manufacturing sector and the service sector. Given the wage assignment $\{w^1, \ldots, w^N\}$ in all the countries, we work out 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 $p_1^{in}(u) = w^i \tau^{in}/Z_1^i$ be the unit

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

cost at which country $i$ sells good $u$ to country $n$ in stage 1. Let $G_1^{in}(p) = Pr(p_1^{in}(u) \leq p)$. It follows that

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

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 is taken as an input into stage 2 production in 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 $\Phi_1^n = \sum_{i=1}^N T_1^i (w^i \tau^{in})^{-\kappa}$. The 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.,

$$\bar{q}_2^n = \exp(\int_0^1 \ln(\tilde{q}_1^n(u))u), \quad \bar{p}_2^n = \exp(\int_0^1 \ln(\tilde{p}_1^n(u))du).$$

By the results of the standard Eaton-Kortum model, the price of the composite intermediate input is given by $\bar{p}_2^n = (\Phi_1^n)^{-\frac{1}{\kappa}}$. Since $\bar{p}_2^n$ is a constant, the unit cost of production in the second step of stage 2 also follows a Fréchet distribution as in stage 1, and is independent across countries. Therefore, the analysis for the first stage also applies to the second stage of production. This makes the model highly tractable. In particular, it allows us to solve the multi-stage Eaton-Kortum model without having to deal with a sum or a product of Fréchet random variables.

For all subsequent stages, i.e., $\forall g \in \{2, \ldots, G\}$, we similarly have

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

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

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

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 $p_s^n(u) = w^n / Z_s^n$ 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

$$P^n(s) = \exp(\int_0^1 \ln(p_s^n(u))du) = (T_s^n)^{-\frac{1}{\kappa}} w^n.$$

As a result, the price for the aggregated consumption basket in country $n$ is $P_F^n = P^n(m)^{\alpha^n} P^n(s)^{1-\alpha^n}$. Then, we can define CPI to be the price of the final consumption basket as follows.

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

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

where $P^n(m) = (\Phi_G^n)^{-\frac{1}{\kappa}}$, $P^n(s) = (T_s^n)^{-\frac{1}{\kappa}} w^n$, and $\Phi_G^n$ is given by a system of equations (1).[19]

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 The PPI definition

The 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 (that are directly sold to final demand). On the other hand, it includes domestically produced intermediate goods.

For output good $u$ produced in stage $g$, $g = 1, \dots, G$, country $n$ purchases 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 the results from a standard Eaton-Kortum model, for $g = 2, \dots, G$, the probability of this event is given by

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

and for the first stage of production, the probability is $\pi_1^{in} = T_1^i[\tau^{in} w^i]^{-\kappa} / \Phi_1^n$.

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 $\pi_g^{in}$ multiplied by its total spending on goods $u$. Since all the goods are symmetric, we have $X_g^{in}/X_g^n = \pi_g^{in}$.

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

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

and for stage 1, the total earnings are

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

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

By the household budget constraint $w^n L^n = P_F^n F^n + TB^n$, the total expenditure for any country $n$ on the outputs of the manufacturing sector produced in the final stage $G$ is given by

$$X_G^n = \alpha^n P_F^n F^n = \alpha^n (w^n L^n - TB^n). \tag{2}$$

Given the final-stage total expenditure $X_G^n$ in country $n$, its total earnings at the end of stage $g$ are given

[19] The variable $\Phi_G^n$ can be derived via forward induction starting from $\Phi_1^n$ in the system of equations (1).

by backward induction, i.e.,

$$E_g^n = \sum_{i=1}^{N} \frac{T_g^n[\tau^{ni}(w^n)^{1-\theta^n}(\Phi_{g-1}^n)^{-\frac{\theta^n}{\kappa}}]^{-\kappa}}{\Phi_g^i} X_g^i, g = 2, \ldots, G, \tag{3}$$

$$X_{g-1}^n = \theta^n E_g^n, g = 2, \ldots, G, \tag{4}$$

and for stage 1, it follows that

$$E_1^n = \sum_{i=1}^{N} \frac{T_1^n[\tau^{ni}w^n]^{-\kappa}}{\Phi_1^i} X_1^i. \tag{5}$$

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 as follows.

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

$$PPI^n = [\exp(\int_0^1 \ln(p_1^n(u))du)]^{\omega_1^n} \cdot \Pi_{g=2}^G [\exp(\int_0^1 \ln(p_g^n(u))du)]^{\omega_g^n}$$

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

where $w_g^n$ is the weight of sales on geometric mean of selling prices in each stage, i.e., $\omega_g^n = E_g^n / (\sum_{g=1}^G E_g^n)$, $g = 1, \ldots, G$, and the earnings $E_g^n$ at stage $g$ are given by backward induction through a system of equations (2)-(5). To clarify, conceptually, the PPI index could also include "service" inputs that are utilized in the manufacturing process, but it does not take the service outputs that directly serve to the final demand into account.

Similar to the definition of CPI, 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 market clears in each country – households' total labor demand in country $n$ must be equal to the total labor supply.[20] The labor demand in country $n$ can be derived from the total earnings in each stage of production. Note that in any stage $g$ of manufacturing production, $g = 2, \ldots, G$, the earnings paid to domestic households in country $n$ are given by $I_g^n = (1 - \theta^n)E_g^n$. Since the only input in the first stage is labor, households' income in the first stage is given by $I_1^n = E_1^n$. Then, the total income for the households in country $n$ is given by

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

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

where $(1 - \alpha^n)(w^n L^n - TB^n)$ is the labor income from the service sector. Thus, the total labor demand in country $n$ is given by $I^n / w^n$.

[20] The goods market clearance is implied in the previous section.

Given exogenous labor supply $L^n$ in country $n$, the labor market clearing condition then requires $I^n/w^n = L^n$. 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.

# 5 Responses of CPI and PPI to productivity and trade-cost shocks

We are now ready to work out how CPI and PPI inflation respond to productivity and trade cost shocks, respectively. We first consider a productivity shock, common to all countries, to a fixed stage in manufacturing production. Then, with an eye for a theoretical prediction that can be tested in the data, we focus on a productivity shock to the first stage of manufacturing production. (We will later use changes in global industrial input prices as a proxy for such an early-stage productivity shock and conduct corresponding empirical testings in Section 6.)

We use $\epsilon_m$ to denote a productivity shock to stage $h$. The location parameter for the stage-$h$ productivity after the shock, $\ln T_h^{'n}$, can be written as the log of the pre-shock location parameter value plus the shock, i.e.,

$$\ln T_h^{'n} = \ln T_h^n + \epsilon_m, \forall n.$$

We use $\epsilon_s^n$ to denote a shock to the service sector productivity, which is unique to country $n$, and $\epsilon_\tau$ to denote a shock to the trade cost, which is common for all countries, respectively, i.e.,

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

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

where $\ln T_s^{'n}$ 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.[21]

For simplicity, we assume, in this section, the same share of intermediate goods in production function for all countries, i.e., $\theta^n = \theta$ for $\forall n$. In the numerical exercise in Section 7, we will relax this assumption and allow country-specific shares of intermediate goods in the production function based on the information in the World Input-Output Database. We conjecture that the equilibrium 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 $\Phi_g^n$, $g \in \{1, \ldots G\}$, after the shocks, it becomes

$$\ln \Phi_g^{'n} = \ln \Phi_g^n - \kappa(1 + \theta + \cdots + \theta^{g-1})\epsilon_\tau \text{ for } g < h, \forall n,$$

$$\ln \Phi_g^{'n} = \ln \Phi_g^n + \theta^{g-h}\epsilon_m - \kappa(1 + \theta + \cdots + \theta^{g-1})\epsilon_\tau \text{ for } g \geq h, \forall n.$$

By the expressions of $X_g$ and $E_g$ in (2)-(5) with the assumption of wage assignment not changing, $X_g$ and

[21] Here we allow domestic trade costs to have a small perturbation around one to facilitate closed-form analyses. In the quantitative analysis of the model in Section 7, we have instead assumed the domestic trade costs to be one, with across-border trade costs being larger than one (as the literature normally does).

$E_g$ for $\forall n$ and $g \in \{1, \dots G\}$ after the shocks become

$$X_g^{'n} = X_g^n, \quad E_g^{'n} = E_g^n,$$

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

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 can verify that the wage assignment of all the countries $\{w^1, \dots, w^N\}$ does not change under either the productivity shocks or the trade cost shocks. This can be understood intuitively in two steps. First, with the Cobb-Douglas utility function, the households always spend a fixed fraction of their income on purchasing the outputs of the service sector. As the firms in the service sector make no profits in competitive markets, if the equilibrium wage does not change, they always require a fixed labor demand, i.e, $(1-\alpha^n)(L^n - TB^n/w^n)$, regardless of their productivity. Second, either a common productivity shock to any fixed stage of manufacturing production or a common shock to trade costs does not affect the comparative advantage in any stage of the 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 log-deviations of CPI and PPI measures in country $n$ after the shocks are thus given by

$$\ln \widehat{CPI}^n = -\frac{1-\alpha^n}{\kappa}\epsilon_s^n - \frac{\alpha^n}{\kappa}\theta^{G-h}\epsilon_m + \alpha^n \frac{1-\theta^G}{1-\theta}\epsilon_\tau, \tag{6}$$

$$\ln \widehat{PPI}^n = -[\sum_{g=h}^{G} \frac{\omega_g^n}{\kappa}\theta^{g-h}]\epsilon_m + [\sum_{g=2}^{G} \omega_g^n \frac{\theta-\theta^g}{1-\theta}]\epsilon_\tau. \tag{7}$$

Inspecting these expressions, a service-sector productivity shock $\epsilon_s^n$ 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 $\epsilon_m$ on CPI inflation becomes smaller relative to that of a country-specific service-sector shock $\epsilon_s^n$.

## 5.1 Comparative statics under productivity shocks

With a focus on productivity shocks, the correlation between the log-deviations of CPI and PPI in country $n$ is given by

$$corr(\ln \widehat{CPI}^n, \ln \widehat{PPI}^n) = [1 + (\frac{1-\alpha^n}{\alpha^n \theta^{G-h}})^2 \frac{var(\epsilon_s^n)}{var(\epsilon_m)}]^{-\frac{1}{2}}. \tag{8}$$

Then, holding constant the variance of the productivity shocks and the fixed stage $h$ that is subject to the productivity shock in the manufacturing sector, since $0 < \theta < 1$, it is clear that this correlation, i.e., $corr(\ln \widehat{CPI}^n, \ln \widehat{PPI}^n)$, is strictly decreasing in the total number of manufacturing stages $G$.[22] Formally, we have Proposition 1.

[22] The comparative statics of increasing $G$ here requires other parameters to hold constant, such as the share of intermediate goods $\theta$ in the production function of manufacturing sector. It may seem that this implies a large increase in the gross output to value-added ratio. But it is not true because of the existence of service sector in the model, which always has only one stage of production. From the data in WIOD, the service sector that directly serves final consumers (as the counterpart of service sector in the model) occupies a large fraction of the whole economy; the expenditure in the service sector nearly takes 40% of the total final consumption for most of countries in WIOD.

**Proposition 1** *Holding constant the variances of the stage-specific productivity shocks in all sectors, as the number of manufacturing stages increases, the correlation between* $\widehat{\ln CPI}$ *and* $\widehat{\ln PPI}$ *decreases.*

While the model is static, we can use this proposition to interpret the correlation between the time series of PPI and CPI. For a given time period, say 1980-2000, and a given country $n$, the expression in Equation 8 describes the correlation between the time series of PPI and CPI within that time period (assuming G is fixed in that sub-period). This correlation is a declining function of G. Since G is higher in the post-2001 period than in the last century, the proposition implies that the correlation between PPI and CPI becomes lower in this century.

Proposition 1 can also be used to interpret the behavior of cross-country correlation between PPI and CPI inflation at a given point in time. That is, in a given year $t$, for a common global productivity shock $\epsilon_m$ and country-specific productivity shocks $\epsilon_s^n$, the expression on the left hand side of Equation 8 is exactly the PPI-CPI correlation across countries for that year. Again, since G is higher in the post-2001 period than in the last century, the proposition implies that the cross-country correlation between PPI and CPI becomes lower in the years after 2001 than those before.

We might also contrast this proposition with what would happen under global simultaneous 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 negatively affected all sectors at the same time.

## 5.2 The case of homogeneous countries

If we impose some symmetry assumptions, we can obtain additional analytical results. In particular, let us assume countries are homogeneous, each with identical labor supply, identical productivity distribution in each stage of manufacturing production, identical productivity distribution in the service sector, i.e., $L^n = L$, $T_g^n = T_g$, $T_s^n = T_s$ for $\forall n$ and $\forall g \in \{1, \ldots, G\}$, identical bilateral trade costs, i.e., $\tau^{in} = \tau$ for $\forall i, n$, and identical service expenditure share in the consumption basket $\alpha^n = \alpha$ for $\forall n$.[23] Under these symmetry assumptions, the wages must be equal across all countries, i.e., $w^n = w$ for $\forall n$. We normalize the wage to be one. In this case, international trade happens because the realizations of productivity are different across countries. With the definitions of $\ln CPI$ and $\ln PPI$, we proceed with Proposition 2.[24]

**Proposition 2** *Given N homogeneous countries 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*

$$\ln CPI = -\frac{1-\alpha}{\kappa} \ln T_s - [\sum_{g=1}^{G} \frac{\alpha}{\kappa} \theta^{G-g} \ln T_g] + \frac{\alpha(1-\theta^G)}{1-\theta} \ln \tau - \frac{\alpha(1-\theta^G)}{\kappa(1-\theta)} \ln N,$$

$$\ln PPI = -[\sum_{g=1}^{G} \frac{\theta^{G-g}(1-\theta)(G-g+1)}{\kappa(1-\theta^G)} \ln T_g] + \frac{\theta - G\theta^G + (G-1)\theta^{G+1}}{(1-\theta)(1-\theta^G)} \ln \tau - \frac{\theta}{\kappa}[\sum_{g=2}^{G} \frac{\theta^{G-g} - \theta^G}{1-\theta^G} \ln N].$$

We can now derive explicit expressions about how CPI and PPI inflation respond to different types of shocks. When more countries participate in international trade, both CPI and PPI inflation will decline due to a better chance of finding lower input costs through outsourcing. This can be seen from the last term in the two equations above.

[23] Due to symmetry across countries, we also impose the assumption of balanced trade in each country $n$, i.e., $TB^n = 0$.
[24] It can be easily verified that, in the current settings, an equilibrium always exists.

### 5.2.1 Productivity shock in the manufacturing sector

Consider a common global shock to the first-stage productivity in the manufacturing production, $\ln T_1$. By Proposition 2, the responses of CPI and PPI are given, respectively, by

$$\widehat{\ln CPI} = -\frac{\alpha}{\kappa}\theta^{G-1}\widehat{\ln T_1}, \quad \widehat{\ln PPI} = -\frac{G}{\kappa}\frac{(1-\theta)\theta^{G-1}}{1-\theta^G}\widehat{\ln T_1}, \tag{9}$$

which yield

$$\frac{\widehat{\ln PPI}}{\widehat{\ln CPI}} = \frac{G(1-\theta)}{\alpha(1-\theta^G)}.$$

It is obvious that the response of CPI inflation to the productivity shock, i.e., $|\widehat{\ln CPI}/\widehat{\ln T_1}| = \frac{\alpha}{\kappa}\theta^{G-1}$, is strictly decreasing with respect to the total number of production 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 production stages. The proofs can be found in Appendix $C$. Furthermore, the right hand side of the expression of $\widehat{\ln PPI}/\widehat{\ln CPI}$ can be shown to be strictly increasing in the number of production stages $G$. Details can be found in Appendix $D$. This implies Proposition 3.

**Proposition 3** *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, and the decline is greater for the CPI inflation.*

### 5.2.2 Common shocks in trade costs

Consider a common shock to trade costs $\ln \tau$. By Proposition 2, the responses of CPI and PPI are given by

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

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

Since $\theta < 1$, CPI inflation would become more responsive to a shock to the trade costs 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 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 become much smaller than the variance of the productivity shocks to the service sector. Otherwise, with an increase in the number of manufacturing production stages, the correlation might increase, as a change in trade costs can affect both the CPI and the PPI inflation more than proportionately.

# 6 Empirical tests

A rise in the length of the production process from the pre-2001 period to the post-2002 period – as documented in both Wang et al. (2017) and Section 2 of the current paper – 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, we now check for empirical validity of other model-predicted consequences of a rise in the production length. In particular, as stated by Proposition 3 in Section 5.2, we will check (a) whether the responsiveness of both CPI and PPI to a common global productivity shock in the first-stage manufacturing production indeed becomes weaker after 2002, and (b) perhaps more importantly, whether the decline in CPI responsiveness is greater than that of PPI responsiveness.

Since the countries in the real world are not symmetric, the closed-form predictions of the model in Section 5.2 might be regarded as an approximation for predictions in an asymmetric world.[25] 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 changes in the global industrial input prices as a proxy for common global productivity shocks in the first-stage manufacturing production. Industrial inputs – metals and raw materials for manufacturing purposes – are disproportionally used in the very early stage of manufacturing production.[26] 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 3 should also hold for a productivity shock to any other fixed stage $h$ 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.

While the model is real, the two inflation indices are often thought of as "nominal" variables. To control for possible effects from national monetary policies, we include time-varying country-specific nominal labor costs. This is in addition to (time-invariant) country fixed effects. The results, reported in Table 2, are qualitatively similar to Table 1. That is, we see a substantial decline in the responsiveness of both PPI and CPI to a given global industrial input price shock from the 1981-2001 period to the 2002-2014 period. Furthermore, a $t$-test rejects the null of equal decline for the two inflation indicators, in favor of a greater one for the CPI inflation. These patterns are consistent with the key predictions of the model.

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.

Appendix Figure $A.4$ 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 onward, and the primary commodity price index, available from 1992 onward, are both constructed and reported by the International Monetary Fund. Both are denominated in

[25] In the case of heterogeneous countries, from Equation 6, 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 is not straightforward for the response of PPI inflation.

[26] 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.$)."

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 inflation around 2001. We thus separate the sample into two sub-samples: 1980-2001 and the other with 2002-2014.

### 6.1 Empirical specification

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

$$\Delta \ln CPI_t^n = \beta_1 \Delta \ln CPI_{t-1}^n + \beta_2 \Delta \ln P_{Industrial,t}^n + X_t^n + \epsilon_{CPI,t}^n, \tag{10}$$

$$\Delta \ln PPI_t^n = \gamma_1 \Delta \ln PPI_{t-1}^n + \gamma_2 \Delta \ln P_{Industrial,t}^n + X_t^n + \epsilon_{PPI,t}^n, \tag{11}$$

where $\Delta \ln P_{Industrial,t}^n$ 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, the interaction of Great Recession dummies with the log-change in industrial input price, 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. In Table 1, the coefficient on changes in industrial input prices, i.e., $\Delta \ln P_{Industrial,t}$, is significantly positive in all columns. This is not surprising.

To shed light on the validity of our story, we compare the evolution 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 decline is greater for the CPI than the PPI. These patterns are consistent with Proposition 3.

To formally test the last statement, we report the ratio of PPI inflation response to the CPI inflation response, i.e., $\frac{\partial \Delta \ln PPI_t / \partial \Delta \ln P_{Industrial,t}}{\partial \Delta \ln CPI_t / \partial \Delta \ln P_{Industrial,t}}$. Table 1 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 decline is significantly greater for CPI than for 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.

As mentioned before, 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, $WageDummy * \Delta \ln wage_t$, in the regression to utilize the information in the full sample set. More specifically, it equals $\Delta \ln wage_t$ if wage data are available; otherwise, it equals 0. As shown 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. While the two inflation indicators are nominal variables, the wedge between the two is driven in part by real factors.

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., $\ln CPI$ and $\ln PPI$, 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 2.2% 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, Moessner, and Takáts (2016) have documented that the pass-through of exchange rate to consumer prices has fallen in emerging market economies 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 Appendix Table $A$.1. While the coefficients before the log-change of industrial input price in Appendix Table $A$.1 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 in Appendix Table $A$.1, and 1.6% 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, Moessner, and Takáts (2016), the coefficients for the exchange rate pass-through are also smaller after 2001.

For a robustness check regarding the Great Recession, we have also controlled the interaction term of Great Recession dummies with the log-change in industrial input prices, e.g., Table 3 and Appendix Table $A$.1, and all the results are robust.

With a lagged dependent variable on the right-hand side in Specification 10 and 11, 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 a robustness check, we also use the Arellano-Bond estimator (Arellano and Bond, 1991) and the LSDV estimator, respectively. 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.[27] More specifically, the weight of the primary commodity price index on industrial inputs price is 18.4%, 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 the manufacturing process and are disproportionately used in the early stages of chemical goods production or energy goods production. 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

[27] More precisely, the food category within the primary commodity price index defined by the IMF includes cereals, vegetable oils or protein meals, meat, seafood, sugar, bananas, and oranges, while the category of beverages includes coffee, cocoa beans, and tea.

more responsive to such a shock than to one in the first stage of manufacturing production only.

Using similar specifications as Specification 10 and 11, we have

$$\Delta \ln CPI_t^n = \beta_1 \Delta \ln CPI_{t-1}^n + \beta_2 \Delta \ln P_{Commodity,t}^n + X_t^n + \epsilon_{CPI,t}^n,$$

$$\Delta \ln PPI_t^n = \gamma_1 \Delta \ln PPI_{t-1}^n + \gamma_2 \Delta \ln P_{Commodity,t}^n + X_t^n + \epsilon_{PPI,t}^n,$$

where $\Delta \ln P_{Commodity,t}^n$ 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, the interaction of Great Recession dummies with the log-change in primary commodity price, 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.

Appendix Table $A.2$ and $A.3$ 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 Appendix Table $A.2$, 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 Appendix Table $A.3$. 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 Discussion on alternative explanations

We now consider some alternative explanations for the reduced correlation between CPI and PPI as well. As a first alternative, if the share of services in the consumption basket rises over time, it could drive a wedge between the two inflation measures and therefore a decline in their correlation.

Our theoretical model has incorporated the effects of changes in service share in final demand on the correlation between CPI and PPI inflation and has confirmed this intuition. From Equation 8, holding constant the variance of the productivity shocks and the fixed stage $h$ that is subject to the productivity shock in the manufacturing sector, and also holding constant the total number of manufacturing stages $G$ and the share of intermediate inputs $\theta$ in each manufacturing stage, it is clear that the correlation between CPI and PPI inflation, i.e., $corr(\widehat{\ln CPI^n}, \widehat{\ln PPI^n})$, is strictly decreasing with respect to the service share $1 - \alpha^n$. Formally, we have Proposition 4.

**Proposition 4** *Holding constant the variances of the stage-specific productivity shocks in all sectors, the total number of manufacturing stages, and the share of intermediate inputs, as the service share in final demand increases, the correlation between* $\widehat{\ln CPI}$ *and* $\widehat{\ln PPI}$ *decreases.*

Recall that the dramatic decline in the CPI-PPI correlation took place around the turn of the century (as reported in Section 2), with virtually no visible change in the correlation before. For the service share to explain this pattern, there needs to be a structural break in the service expenditure share in the direction of a much higher share in the new century. We check this prediction using data in WIOD. Appendix Figure $A.5$ presents the results for the largest advanced and emerging market economies. This prediction is not supported in the data. In fact, in China, Japan, the United Kingdom, India, and the European Union, the changes in the service share after 2001 appear to be below the pre-2001 trend. (The dashed lines in the graph represent a country-specific trend constructed from the 1995-2001 data.)

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 service share explanation did matter a lot for the CPI-PPI correlation, its steady increase observed in the pre-2001 period appears to be inconsistent with a near constant correlation in that period in Figure 1.

Switching to data for OECD countries, the median share of services (excluding housing) in the CPI basket, reported in Appendix Figure $A.6$, also shows that the post-2001 increase is below a simple linear trend. These patterns suggest that the changes in the service share are unlikely to have played a major role in explaining a dramatic decline in the correlation between CPI and PPI after 2001.

From Equation 9, holding the total number of manufacturing stages $G$ and the share of intermediate inputs $\theta$ constant, the response of CPI inflation to the productivity shock in the first stage of manufacturing production, i.e., $|\widehat{\ln CPI}/\widehat{\ln T_1}| = \alpha\theta^{G-1}/\kappa$, is strictly decreasing with respect to the service share $1-\alpha$. Meanwhile, the response of PPI inflation to the productivity shock does not change with respect to the service share $1-\alpha$. This implies Proposition 5.

**Proposition 5** *As the service share in final demand increases, CPI inflation becomes less responsive to a common global productivity shock in the first stage of manufacturing production, while the PPI inflation exhibits no change in the responsiveness.*

However, our empirical results in Section 6.1 indicate a statistically significant decline in the responsiveness of PPI inflation to global industrial input prices. Thus, even if a higher service share has contributed to the divergence between CPI and PPI inflation, we will still need something like a lengthening of global supply chains to explain changes in the PPI responsiveness to global input price shocks.

The second alternative explanation has to do with a particular aspect of globalization. Globalization could lead to more competition and therefore a lower markup. If this force 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 inflation measures. However, recent work by Autor et al. (2020) and De Loecker and Eeckhout (2020) suggest that globalization may have led to an increase rather than a decrease in the markup. More importantly, this story also has other testable implications. In particular, with a decline in the markup for manufacturing goods than for service items, it should make both PPI and CPI more responsive to changes in global industrial input prices. As our empirical work reveals, this implication is not supported in the data. In particular, we see that both CPI and PPI have empirically become less responsive to global industrial input prices since the turn of the century. This data pattern is consistent with the longer production chain story but inconsistent with the markup story.

Having said this, it is important to note that our production chain story and these alternative stories are not necessarily mutually exclusive. All these developments could take place simultaneously. Since the longer production chain hypothesis has not been previously explored in the literature, we focus on developing this story and testing its empirical implications rather than developing and then excluding the alternative stories.

# 7 Quantitative analysis of the model

We have so far used the model to derive qualitative predictions about the average behavior of PPI and CPI. We now attempt to perform a more ambitious exercise, which is to derive model implications for country-specific elasticities of the inflation measures with respect to a first-stage productivity shock and compare them to empirically estimated country-specific elasticities. If our theory is a useful description of the world, we should expect to see a positive correlation between the model-implied and empirically estimated elasticities.

To generate the model-implied elasticities, we use our model and the World Input-Output Database (WIOD). The implied elasticities vary by country because the trade costs, production stage-specific productivities, shares of intermediate inputs in the production, and shares of services in the consumption, all backed out from the WIOD, vary by country. Note that the construction of the WIOD does not use CPI or PPI data series.

To generate the empirical estimates of the elasticities, we regress, for each country, its PPI or CPI inflation series on changes in the global industrial input prices (with other control variables). This procedure does not use our model or the WIOD data. Because the two sets of elasticities are drawn from two different data sources, if our model were a bad description of the world, there is no guarantee that the two sets are positively correlated.

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 5.2. We verify that Proposition 3, which 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 the inflation measures across countries, this section can attempt something more audacious – checking whether the empirical data patterns at the level of individual countries are consistent with the model predictions that allow for country heterogeneity.

To study the average behavior of CPI and 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 CPI and PPI responses and to take into account the 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 $\{\theta^n, \alpha^n\}$; trade balance $\{TB^n\}$, 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 $\kappa$ for the productivity distributions.

The WIOD database covers 40 countries, including the most important economies in the world in terms of either GDP or volume of international trade.[28] We use the 1998 WIOD data to calibrate the model predictions for the pre-2001 period and the 2005 WIOD data for the post-2001 period. As a robustness check, we also use the 1997 and 2006 WIOD data, respectively, to generate model predictions for the pre-2001 and post-2001 periods. That turns out to make virtually no difference.

## 7.1 Calibrations

For the share parameters in the production function, country-specific $\theta^n$ is set to match the share of manufacturing inputs in total intermediate inputs for each country in WIOD in 1998 and 2005, respectively. Similarly, country-specific $\alpha^n$ is set to match the share of the expenditure on manufacturing goods in the total consumption basket for each country in 1998 and 2005, respectively.[29]

The model assumes that the productivity in a given stage, sector, and country is independently drawn

[28] The WIOD has 40 countries plus a composite "rest of the world."

[29] The first 19 sectors in WIOD are defined as manufacturing activities, while the remaining 16 sectors are classified as service sectors.

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 to be $\kappa = 4.12$. In addition, country-specific $TB^n$ is set to match the actual trade balance for each country, which equals to the total value added minus the total final consumption expenditure for the relevant year.[30]

As rescaling the location parameters for all countries does not alter any country's comparative advantage, it does not affect the quantity assignment in the equilibrium or the 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 $g = 1, \ldots, G$. Other countries' technology parameters are measured relative to those of the United States.

While the technology parameters in the manufacturing sector are estimated from the observed bilateral trade shares in intermediate goods and final goods, the service sector productivity cannot be estimated in the same way since the service output is not directly traded. Instead, we assume the location parameter for service sector productivity in a country to be a geometric average of the location parameters across all manufacturing stages in the same country, i.e., $T_s^n = \exp[(\sum_{g=1}^{G} \ln T_g^n)/G]$ 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 plays no role in the calibrated responses of CPI or PPI to a first-stage productivity shock in manufacturing sector.

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 $\pi_G^{in}$ is the bilateral trade share in terms of final goods, or more precisely, the spending by country $n$ on the final goods produced in country $i$ divided by total spending of country $n$ on all final goods. Details on the construction of the bilateral trade shares are described later. This method of calibrating the trade costs is used by Antràs and de Gortari (2020).

To summarize, there are $G(N-1)$ number of location parameters representing productivities, i.e., $\{T_{g=1,\ldots,G}^n\}_{n=2}^N$. To back out these parameters, we match the expenditures 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 $\{T_{g=1,\ldots,G}^n\}_{n=2}^N$, the model generates 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 between the model-predicted bilateral trade shares and their empirical counterparts.

The first 19 sectors in WIOD are defined as "manufacturing activities" and aggregated into a single

[30] We use the ratio of country-specific trade balance to value-added from WIOD to proxy the share of $TB^n/w^nL^n$ in the model.

"manufacturing sector," while the remaining 16 service sectors are aggregated into a single "service sector."[31] Since the final goods 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.[32]

The number of stages in manufacturing production is exogenous in the model. We assume $G=2$ for the pre-2001 period and $G=4$ for the post-2001 economy. As a robustness check, we also use $G=3$ for the post-2001 period to check the robustness of Proposition 3 (with a detailed discussion in Section 7.2).[33] (We will report later, by comparing model-implied elasticities of the price indices with respect to the first-stage productivity under various values of G and their empirical counterparts, that $G=2$ for the pre-2001 period and $G=4$ for the post-2001 period are the most reasonable assumptions.)

The model is over-identified in all cases. Table 4 summarizes the calibrated parameters. Appendix Tables $A.4$ and $A.6$ report the estimates of the productivity location parameters in 1998 and 2005, respectively.

This is a nonlinear system with about one hundred parameters to be estimated. We estimate the model by the method of moments. We adopt a simulated-annealing algorithm in optimization (Bertsimas and Tsitsiklis, 1993), which introduces a probability of jumping out of local optimums, in order to search for a global optimum.

## 7.2 The log-deviations of CPI and PPI to a manufacturing productivity shock

Given the calibrated parameters in this section, we generate model-predicted responses of CPI and PPI inflation to a productivity shock in the first-stage of manufacturing production. Table 5 shows the log-deviations of CPI and PPI, respectively, in response to a first-stage productivity shock and illustrates the ratio of $\Delta \ln PPI/\Delta \ln CPI$ as the length of the global value chain becomes larger.

From Table 5, as the number of production stages increases from 2 to 4, the log-deviations of both CPI and PPI become less responsive as illustrated in Column 1-2 and 4-5 of Table 5. In addition, the decline in sensitivity is greater for CPI than for PPI. Specifically, we can reject the null hypothesis, with a $p$-value of 0.01%, that the mean of $\Delta \ln PPI/\Delta \ln CPI$ ratio in Column (6) is the same as in Column (3), in favor of the alternative that the $\Delta \ln PPI/\Delta \ln CPI$ ratio in 2005 is significantly greater on average than those in 1998. These patterns are in line with the theoretical predictions in Proposition 3.

As a robustness check, we also generate the model-predicted responses of CPI and PPI inflation under the assumption of $G=3$ in the pre-2001 period. Appendix Table $A.6$ reports the estimated productivity location parameters in this case. Appendix Table $A.7$ reports the log-deviations of CPI and PPI in response to a first-stage productivity shock, respectively. As before, we can reject the null hypothesis that the mean of $\Delta \ln PPI/\Delta \ln CPI$ ratio in Column (6) is the same as that in Column (3), in favor of the alternative that the $\Delta \ln PPI/\Delta \ln CPI$ ratios in 2005 are significantly larger, on average, than those in 1998 with a $p$-value 0.4%. To summarize, the key conclusion is that as the number of production stages increases, both CPI and PPI become less responsive, and the reduction in the responsiveness of CPI is more than that of PPI.

[31] The conclusions in this section are robust when we take all 35 sectors in WIOD as the manufacturing sector in producing intermediate goods.

[32] When we estimate the bilateral trade shares predicted by the model, we use population data in 1998 and 2005, respectively, from the Penn World Table 9.0 to proxy for labor supply. Following Johnson and Moxnes (2019), we construct relative wages across countries by total household consumption (in WIOD) divided by total labor supply.

[33] This is consistent with Antràs and de Gortari (2020). For the pre-2001 period, the data can easily reject the case of $G=1$, because it would have implied identical responses of the PPI to the global first-stage productivity shock, which are inconsistent with the data. Following Antràs and de Gortari (2020), we set $G=2$ for the pre-2001 period.

### 7.3 The empirical country-specific inflation responses to changes in global industrial input prices

We next explore cross-country heterogeneity in the responses of CPI and PPI inflation, respectively, to changes in global industrial input prices. Specifically, we pursue the following empirical specification:

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

$$\Delta \ln PPI_t^n = \gamma_1 \Delta \ln PPI_{t-1}^n + I^n \cdot \gamma_2^n \Delta \ln P_{Industrial,t}^n + X_t^n + \epsilon_{PPI,t}^n,$$

where $I^n$ is a country dummy variable and $X_t^n$ represents other control variables including the log-change in wage per hour and country fixed effects. All the variables are denominated in nominal terms and local currency. $\beta_2^n$ and $\gamma_2^n$ are the country-specific CPI and PPI elasticities of interest, respectively.[34]

Appendix Figure $A.7$ summarizes the distribution of the estimated CPI and PPI elasticities to industrial input prices across the WIOD countries. Going from Column 1 to Column 2, we see that both CPI and PPI elasticities have declined after 2001. In addition, for the pre-2001 period, the dispersion of the CPI elasticity, measured by the standard derivation, is 0.165, which is substantially smaller than the dispersion of the PPI elasticity at 0.266. Similarly, for the post-2001 period, the dispersion of CPI elasticity (0.038) is also substantially smaller than the dispersion of PPI elasticity (0.074). Thus, the cross-country heterogeneity is much smaller for the CPI response compared with the PPI response.

### 7.4 Model predictions versus empirical estimates

We now explore heterogeneity across countries. In particular, for a fixed number of stages of production (say $G = 2$), the model generates a theoretically predicted elasticity of the CPI index with respect to the first-stage manufacturing productivity. The model-implied elasticity differs by country due to differences in the share of intermediate inputs in total production and the share of the services in the consumption basket, which can be calculated directly from the World Input-Output Data (WIOD), and the variations in country–pair-specific trade costs and the relative upstreamness of each country's production, which are implied by the theoretical model in combination with the observed trade patterns in WIOD. For concreteness, the model-implied elasticities are calculated by using the 1998 WIOD for the pre-2001 period, and the 2005 WIOD for the post-2001 period.

Separately, for each country, we estimate the elasticity of CPI of that country with respect to a change in the global industrial input price prices. For the pre-2001 period, we use annual data on CPI and global industrial input price index during 1980-2001. For the post-2001 period, we use the data during 2002-2014. The empirical elasticities also differ by country and time period.

We then test the null hypothesis that the model-implied and empirically estimated elasticities are uncorrelated against the alternative that the correlation is positive. This is a demanding test as the two calculations use completely different data. In particular, the model-implied elasticities use the model and the WIOD, but not CPI series. In contrast, the empirical elasticities are estimated by regressing the change

[34] We adopt an LSDV estimator for the regressions incorporating country-specific CPI and PPI responses. Note that estimators for dynamic panel data such as QML do not apply here. From the econometric theory, the asymptotic assumptions for those dynamic panel estimators (i.e., given a finite time period T, the number of groups N goes to infinity) do not hold. For the specific regressions in this section, if N goes to infinity, the number of independent variables also goes to infinity. On the other hand, as shown in the tables in Section 6, the auto-correlation for PPI is weak. This suggests that the LSDV estimator would not generate a strong bias. In addition, we have employed a corrected LSDV estimator following Judson and Owen (1999) and found essentially the same results.

in log CPI on the change in log global industrial input prices (with control variables as described in Section 7.3), without using either the theoretical model or the WIOD data.[35] If our theoretical model is not a useful description of the world, or imposes too many restrictions, there is no guarantee that the two sets of numbers are positively related.

Column 1 of Table 6 reports that the correlation between the theoretical and empirical estimates is 0.38 for the pre-2001 period under the assumption that the number of production stages $G = 2$. We can reject the null of zero correlation at the 5% level in favor of the alternative that the correlation is positive. This suggests that our model carries some useful information that helps to predict cross-country heterogeneity in the CPI elasticities observed in the data.

We similarly compute the theoretical PPI elasticity (still under the assumption of $G = 2$) in the pre-2001 period and compare it to the empirical estimate (from regressing change in log PPI on change in log global industrial input price index, with control variables described in Section 7.3). Their correlation, reported in the lower panel of the same table, is 0.53, and is statistically significant at the 1% level. These results suggest that our theoretical model carries useful information in predicting the elasticities of both PPI and CPI.

Since the theoretical predictions are generated based on an assumed number of production stages, we also vary the value of $G$ from 2 to 3, 4, and 5. The corresponding correlations between the theoretical and empirical elasticities for the pre-2001 period in these cases are reported in Columns 2-4. In all cases, we can reject the null of zero correlation in favor of a positive correlation at the 5% level. In other words, they all suggest that the theoretical model carries useful information.

Based on the point estimates of either the correlations or the $R^2$, it appears that the assumption of $G = 2$ produces the best match between the model and the empirics for the pre-2001 period, for both the CPI elasticities and the PPI elasticities, relative to $G = 3$, 4, or 5. (When we attempt to test formally if the correlation is higher under $G = 2$ than under the alternative values of $G$, we find that the power of the test is too low for us to discriminate among them.) We note that, based on the model fit to the bilateral trade data, Antràs and de Gortari (2020) also suggest that $G = 2$ is a good description of the data (based on their structural model). They do not perform a formal statistical test of $G = 2$ against alternative values.

We do similar comparisons between model predictions and empirically estimated elasticities for the post-2001 period. For the number of production stages in the model, we vary $G$ (= 2, 3, 4, 5 and 6). The correlations between the theoretical and empirically estimated elasticities are reported in the right half of Table 6. The correlations are positive and statistically significant at the 5% level in all cases except for $G = 2$. The correlations on the CPI elasticities in the post-2001 period, reported in the upper right part of the table, are between 0.11 and 0.45. Judging from the size of the correlation (or the value of $R^2$), the data suggests that $G = 5$ provides the best fit, followed by $G = 4$. (As before, the power of a t-test is too low for us to discriminate various values of $G$ formally.)

The correlations on the PPI elasticities in the post-2001 period, reported in the lower right part of the table, are between 0.25 and 0.36, and the values of $R^2$ are between 6.1% and 13.2%. Based on the point estimates of both the $R^2$ and the correlation, the data suggests that $G = 4$ provides the best fit. Combining the information from the PPI and CPI results, we conclude that $G = 4$ for the post-2001 period may provide the best fit between the model and the data.

To summarize, this exercise confirms that our theoretical model carries useful information for predicting not only the average responses of CPI and PPI to changes in global industrial input price prices, but also

[35] There is some variation in the start date of the CPI inflation series due to data availability.

cross-country heterogeneity in these responses. In other words, in spite of the fact that the model predictions and the empirical estimates draw on two independent data sources, the cross-country patterns are consistent with each other. In particular, those countries that are predicted to have a stronger CPI (or PPI) response by the model also tend to exhibit a stronger CPI (or PPI) response in the data.

In addition, the exercise also provides some evidence that the average number of production stages has increased from the pre-2001 world (with $G = 2$) to the post-2001 world (with $G = 4$). This further bolsters the central point of the paper that an increase in $G$ has played a role in the observed weakening in the relationship between PPI and CPI.

# 8 Concluding remarks

If PPI and CPI inflation indices diverge, the optimal monetary policy as suggested by the literature needs to incorporate PPI inflation as a targeting variable. Using PPI as a forecasting variable for CPI is insufficient. This paper documents, for the first time in the literature, that a qualitative change has occurred in the correlation between the two inflation measures. In the previous century, the correlation was very high, and as a consequence, which inflation index to be put in the monetary policy rule is not important in practice. However, since the start of this century, the two inflation indices have diverged. This can greatly exacerbate the shortcoming of a monetary policy rule that targets CPI inflation only, but not directly PPI inflation (as highlighted by Galí and Monacelli, 2005; Huang and Liu, 2005; De Paoli, 2009; and Wei and Xie, 2020).

How important it is for central banks to revise their policy rule depends also on whether the divergence of the two inflation indices is structural (permanent) or transitory. This paper proposes a structural explanation for the divergence between the two inflation indicators based on a rise in the global value chains. The key idea is that, as the vertical specialization becomes stronger, i.e., with an increase in the average number of production stages in the world economy, more intermediate goods enter the national PPI basket. As a result, the common component in the two price indexes (i.e., domestically consumed final goods which are also domestically produced) becomes a smaller fraction 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) that is likely to stay.

We build a multiple-production-stage version of the Eaton-Kortum multi-country model to illustrate this intuition and take the model predictions to the data. Besides a fall in the correlation between PPI and CPI (which is predicted by the model and observed in the data), we also confirm other predictions of the model. First, by using industrial input price as a proxy for an upstream productivity shock, we find that both CPI and PPI inflation become less responsive to such shock in the post-2001 period than in the pre-2001 period. Second, the reduction in the sensitivity is greater for CPI than for PPI. The results are robust when controlling for labor cost, price level, and nominal exchange rate.

We also attempt a more demanding exercise by examining cross-country heterogeneity in the elasticities of the CPI and PPI series (among 40 countries covered in the WIOD) with respect to global industrial input price changes. 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 CPI and PPI elasticities with respect to a shock to the first-stage manufacturing productivity. These responses are country-specific because countries differ in intermediate input shares, service shares in consumption baskets, trade costs, and relative upstreamness of production along the global supply chain. Separately, from nationally reported CPI and PPI series, we estimate country-specific CPI and PPI responses to changes in the global input price index. Putting the two together, we can reject the null of zero correlation between the model-implied and empirically estimated CPI and PPI elasticities, at the 5% level, in favor of the alternative of a positive association. There is also evidence from our exercise that the number of production stages has increased from the pre-2001 period to the post-2001 period.

It is worth noting that the story proposed in this paper about the divergence between CPI and PPI inflation can be told qualitatively in a closed-economy setting. One could do a similar exercise as in this paper by looking at sectoral data. Nevertheless, the observed increase in the segmentation of production after 2001 has been greatly facilitated by offshoring and international trade, including the rise of China and Eastern Europe as platforms for production and exports. Indeed, the patterns documented in Wang et al. (2017) suggest that a major part of the increase in global production length is an increase in cross-border trade in intermediate inputs. 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 and monetary policies.

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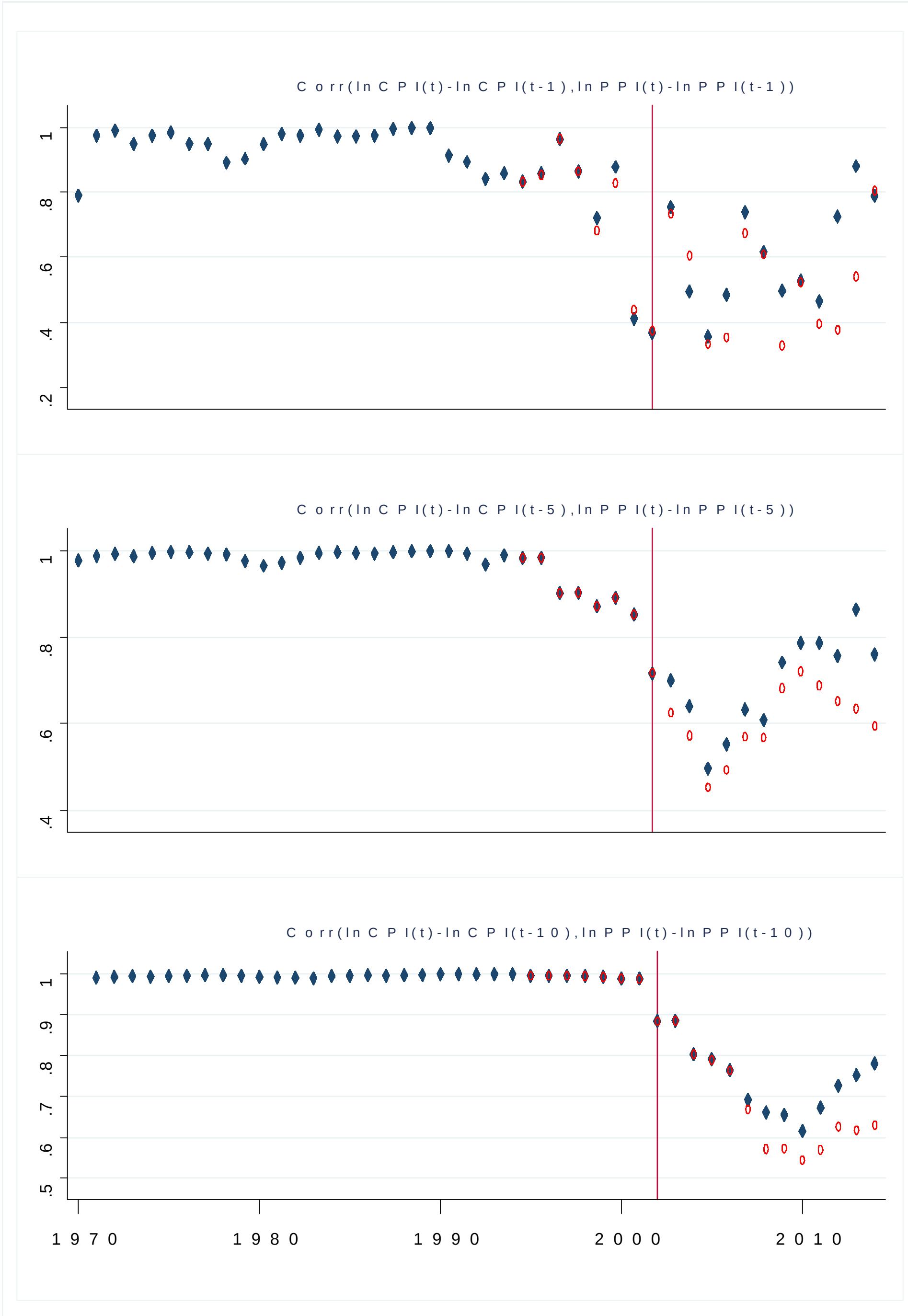



Figure 1: The correlation between CPI and PPI over time

*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 2002.

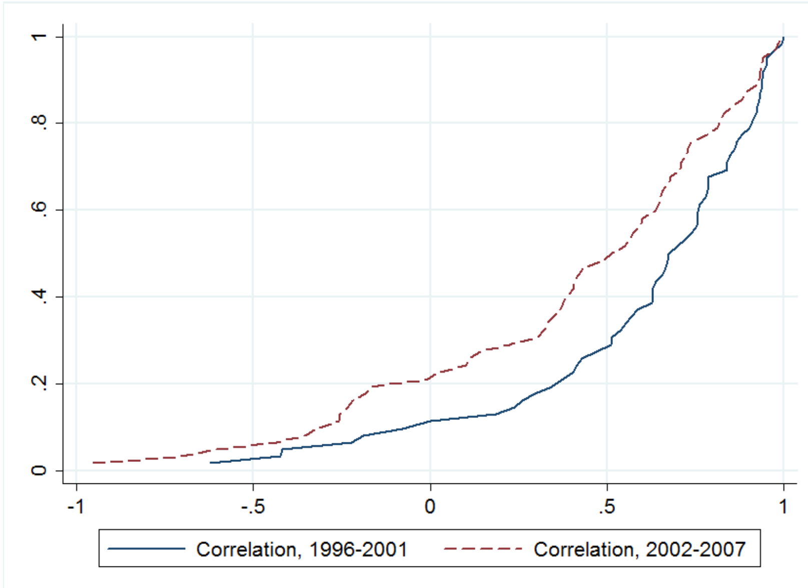



Figure 2: Cumulative distribution of 6-year time-series correlation, constant sample since 1995

*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 the set of countries.


Figure 3: 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 two periods among high-income countries (defined by World Bank in 2017) before the 2008 financial crisis. For comparability, we use the common set of countries for all three time periods, and thus 37 countries are included in the sample.

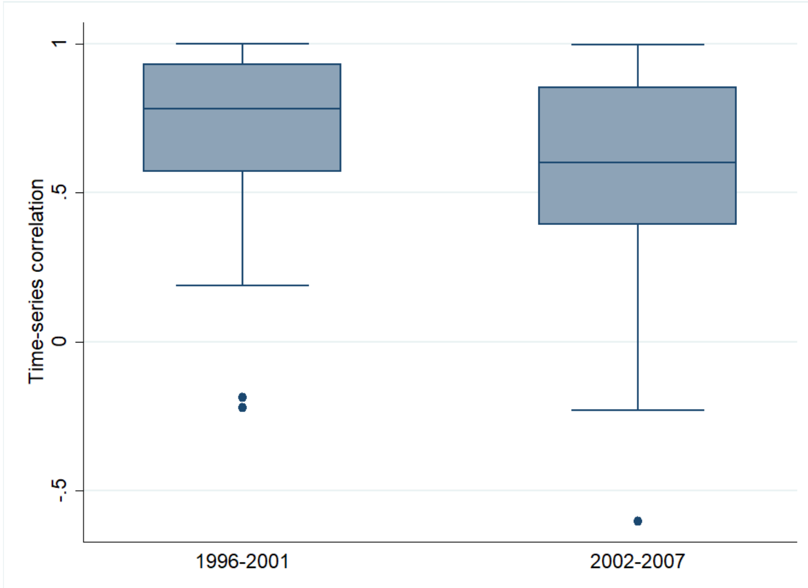



Figure 4: Time-series correlations across developing countries, constant sample since 1995

*Notes*: This figure displays the cross-country distributions of the country-specific time-series correlation between CPI and PPI inflation for the two periods among developing countries (consisting both of middle-income and low-income countries, defined by World Bank in 2017) before the 2008 financial crisis. For comparability, we use the common set of countries for all three time periods, and thus 25 countries are included in the sample.

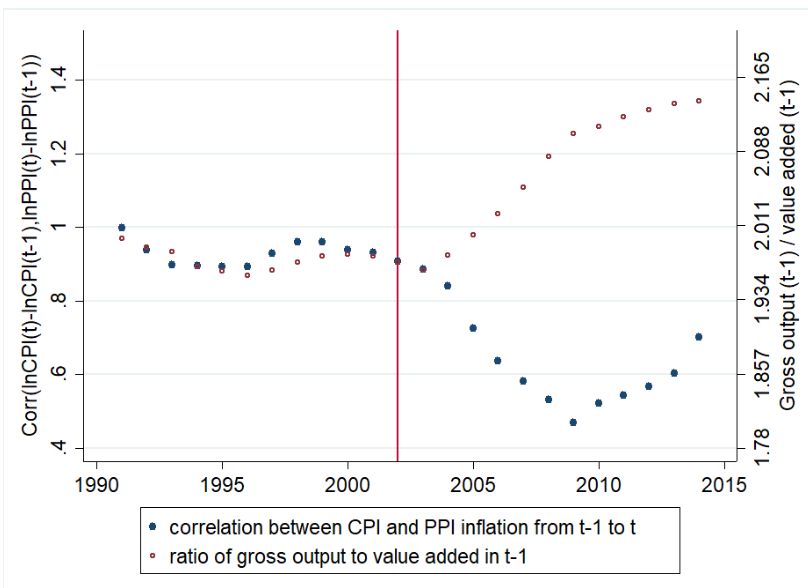



Figure 5: The correlation between CPI and PPI inflation across countries and the total gross output to value-added ratio over time

*Notes*: This figure displays the correlation between CPI and PPI inflation across sample countries over time and the total gross output to value-added ratio. The country sample keeps constant since 1990, and the total gross output to value-added ratio is calculated in each year by aggregating all the countries in the sample together. Both data series have been smoothed by taking 5-year moving average.

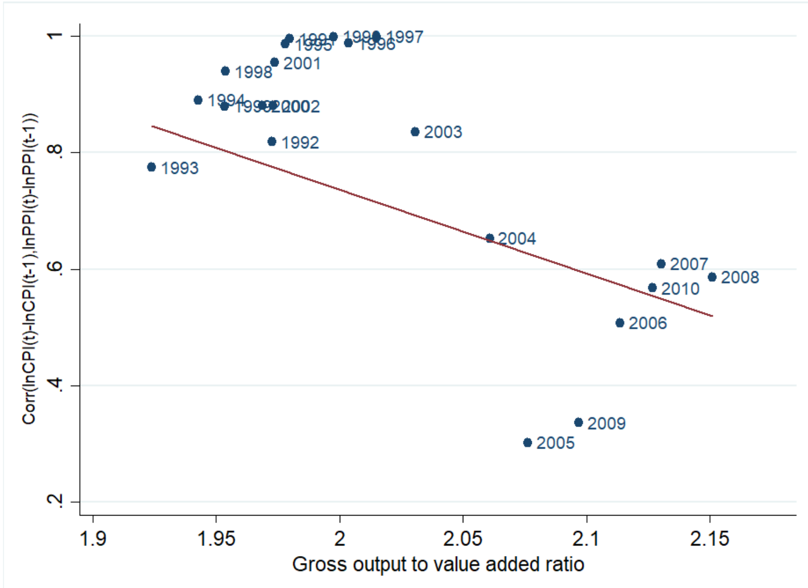



Figure 6: The correlation between CPI and PPI inflation across countries against the total gross output to value-added ratio

*Notes*: This figure displays the correlation between CPI and PPI inflation across sample countries with respect to the total gross output to value-added ratio. The country sample keeps constant since 1990, and the total gross output to value-added ratio is calculated in each year by aggregating all the countries in the sample together.

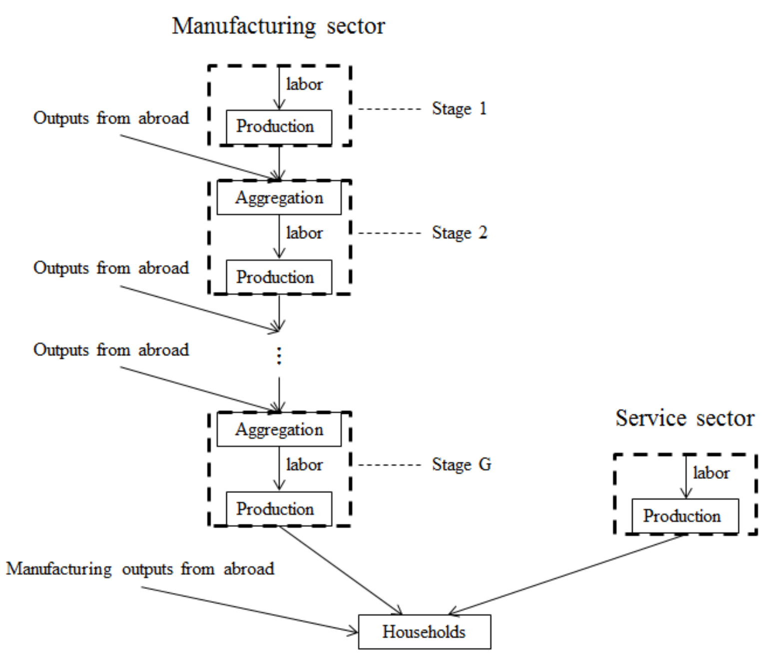



Figure 7: Production structure

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

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 |
|---|---|---|---|---|---|---|
| $\Delta \ln P_{Industrial,t}$ | 0.557*** | 0.743*** | 0.034*** | 0.160*** | 0.043*** | 0.170*** |
| | (0.106) | (0.094) | (0.009) | (0.020) | (0.010) | (0.022) |
| $\Delta \ln CPI_{t-1}$ | 0.329*** | | 0.471*** | | 0.504*** | |
| | (0.062) | | (0.073) | | (0.078) | |
| $\Delta \ln PPI_{t-1}$ | | 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., $\frac{\partial \Delta \ln PPI_t / \partial \Delta \ln P_{Industrial,t}}{\partial \Delta \ln CPI_t / \partial \Delta \ln P_{Industrial,t}}$. 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 |
|---|---|---|---|---|---|---|
| $\Delta \ln P_{Industrial,t}$ | 0.412*** | 0.425*** | 0.031*** | 0.157*** | 0.042*** | 0.170*** |
| | (0.142) | (0.075) | (0.009) | (0.021) | (0.010) | (0.023) |
| $\Delta \ln CPI_{t-1}$ | 0.233*** | | 0.442*** | | 0.482*** | |
| | (0.046) | | (0.067) | | (0.074) | |
| $\Delta \ln PPI_{t-1}$ | | 0.053 | | 0.158*** | | 0.209*** |
| | | (0.061) | | (0.049) | | (0.048) |
| $WageDummy * \Delta \ln wage_t$ | 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, $WageDummy * \Delta \ln wage_t$, equals $\Delta \ln wage_t$ 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., $\frac{\partial \Delta \ln PPI_t / \partial \Delta \ln P_{Industrial,t}}{\partial \Delta \ln CPI_t / \partial \Delta \ln P_{Industrial,t}}$. 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 |
|---|---|---|---|---|---|---|
| $\Delta \ln P_{Industrial,t}$ | 0.397*** | 0.428*** | 0.032*** | 0.138*** | 0.037*** | 0.143*** |
| | (0.130) | (0.077) | (0.009) | (0.016) | (0.010) | (0.019) |
| $\Delta \ln CPI_{t-1}$ | 0.233*** | | 0.434*** | | 0.480*** | |
| | (0.044) | | (0.062) | | (0.071) | |
| $\Delta \ln PPI_{t-1}$ | | 0.053 | | 0.120*** | | 0.172*** |
| | | (0.062) | | (0.045) | | (0.043) |
| $\ln CPI_{t-1}$ | -0.010*** | | 0.004 | | 0.007 | |
| | (0.004) | | (0.006) | | (0.006) | |
| $\ln PPI_{t-1}$ | | -0.002 | | -0.017 | | -0.016 |
| | | (0.005) | | (0.012) | | (0.011) |
| $WageDummy * \Delta \ln wage_t$ | 0.443*** | 0.523*** | 0.160*** | 0.202*** | 0.095*** | 0.101* |
| | (0.128) | (0.083) | (0.030) | (0.058) | (0.025) | (0.056) |
| $Year2008$ | | | | | 0.058*** | 0.101*** |
| | | | | | (0.006) | (0.013) |
| $Year2009$ | | | | | -0.004 | -0.032 |
| | | | | | (0.007) | (0.020) |
| $Year2008 * \Delta \ln P_{Industrial,t}$ | | | | | 0.167*** | 0.193** |
| | | | | | (0.049) | (0.086) |
| $Year2009 * \Delta \ln P_{Industrial,t}$ | | | | | 0.133*** | 0.191 |
| | | | | | (0.041) | (0.170) |
| # Obs. | 1,448 | 881 | 1,407 | 1,046 | 1,407 | 1,046 |
| Ratio of Response ($R$) | 1.078 | | 4.313 | | 3.865 | |
| $R_{post,2001} - R_{pre,2001}$ | | | 3.235 | | 2.787 | |
| $P$-value, H0 : $\Delta R \leq 0$ | | | 1.6% | | 2.2% | |

*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, $WageDummy * \Delta \ln wage_t$, equals $\Delta \ln wage_t$ 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, $Year2008 * \Delta \ln P_{Industrial,t}$, is the interaction of variable $Year2008$ and $\Delta \ln P_{Industrial,t}$. Variable, $Year2009 * \Delta \ln P_{Industrial,t}$, is the interaction of variable $Year2009$ and $\Delta \ln P_{Industrial,t}$. 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., $\frac{\partial \Delta \ln PPI_t / \partial \Delta \ln P_{Industrial,t}}{\partial \Delta \ln CPI_t / \partial \Delta \ln P_{Industrial,t}}$. Country-clustered robust standard errors are reported in parentheses. *** denotes $p < 0.01$, ** denotes $p < 0.05$, while * denotes $p < 0.1$.

Table 4: Calibration of some parameters

| Value | Source/Target |
|---|---|
| $\kappa = 4.12$ | Fréchet distribution shape parameter following Simonnovska and Waugh (2014) |
| $\theta^n$ | Share of manufacturing inputs in total intermediate inputs in WIOD |
| $\alpha^n$ | Share of manufacture goods in household final consumption in WIOD |
| $G = 2$ | Number of production stages in 1998 |
| $G = 3$ | Number of production stages in 2005 |

Table 5: The elasticities of CPI and PPI inflation 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) | (5) | (6) |
| | $\Delta \ln CPI(\%)$ | $\Delta \ln PPI(\%)$ | $\frac{\Delta \ln PPI}{\Delta \ln CPI}$ | $\Delta \ln CPI(\%)$ | $\Delta \ln PPI(\%)$ | $\frac{\Delta \ln PPI}{\Delta \ln CPI}$ |
| Australia | 4.79 | 9.53 | 1.99 | 1.54 | 3.14 | 2.04 |
| Austria | 4.84 | 9.31 | 1.92 | 1.22 | 3.00 | 2.45 |
| Belgium | 5.08 | 9.62 | 1.90 | 1.41 | 3.05 | 2.16 |
| Bulgaria | 8.08 | 17.81 | 2.20 | 1.54 | 6.55 | 4.25 |
| Brazil | 4.08 | 15.05 | 3.69 | 1.24 | 5.35 | 4.32 |
| Canada | 4.22 | 9.29 | 2.20 | 1.43 | 2.86 | 2.00 |
| China | 10.62 | 18.96 | 1.78 | 3.49 | 12.72 | 3.65 |
| Cyprus | 4.51 | 9.72 | 2.16 | 1.14 | 2.82 | 2.48 |
| Czech Republic | 7.16 | 14.57 | 2.04 | 1.72 | 5.67 | 3.29 |
| Germany | 5.02 | 10.20 | 2.03 | 1.37 | 2.91 | 2.12 |
| Denmark | 4.36 | 7.88 | 1.81 | 1.22 | 2.06 | 1.70 |
| Spain | 5.03 | 13.30 | 2.65 | 1.34 | 3.76 | 2.81 |
| Estonia | 5.38 | 14.55 | 2.70 | 1.09 | 3.34 | 3.07 |
| Finland | 3.85 | 11.31 | 2.94 | 1.11 | 3.59 | 3.24 |
| France | 5.29 | 9.15 | 1.73 | 1.43 | 2.67 | 1.87 |
| United Kingdom | 4.81 | 7.78 | 1.62 | 1.30 | 3.01 | 2.31 |
| Greece | 4.76 | 10.18 | 2.14 | 1.18 | 2.39 | 2.02 |
| Hungary | 7.10 | 16.67 | 2.35 | 1.63 | 4.16 | 2.54 |
| India | 7.27 | 16.95 | 2.33 | 1.76 | 6.22 | 3.54 |
| Indonesia | 8.23 | 17.35 | 2.11 | 2.49 | 11.95 | 4.80 |
| Ireland | 5.15 | 10.02 | 1.94 | 1.30 | 2.30 | 1.77 |
| Italy | 5.75 | 10.49 | 1.82 | 1.51 | 2.56 | 1.69 |
| Japan | 3.63 | 11.13 | 3.06 | 1.20 | 4.44 | 3.69 |
| Korea | 4.69 | 17.20 | 3.67 | 1.67 | 8.36 | 5.02 |
| Lithuania | 7.37 | 18.50 | 2.51 | 1.71 | 4.83 | 2.82 |
| Luxembourg | 5.04 | 4.83 | 0.96 | 1.31 | 0.80 | 0.61 |
| Latvia | 5.42 | 14.17 | 2.61 | 0.93 | 3.06 | 3.29 |
| Mexico | 5.38 | 17.50 | 3.25 | 1.53 | 5.69 | 3.72 |
| Malta | 6.51 | 15.72 | 2.41 | 1.67 | 2.78 | 1.67 |
| Netherlands | 4.61 | 9.29 | 2.02 | 1.27 | 2.79 | 2.19 |
| Poland | 5.90 | 15.60 | 2.65 | 1.24 | 3.44 | 2.77 |
| Portugal | 5.25 | 14.49 | 2.76 | 1.34 | 3.21 | 2.39 |
| Romania | 8.42 | 18.08 | 2.15 | 1.80 | 4.96 | 2.76 |
| Russian Federation | 6.43 | 16.07 | 2.50 | 1.40 | 4.32 | 3.08 |
| Slovakia | 6.27 | 20.93 | 3.34 | 1.83 | 5.18 | 2.83 |
| Slovenia | 6.22 | 13.77 | 2.21 | 1.37 | 4.22 | 3.08 |
| Sweden | 4.22 | 8.96 | 2.12 | 1.34 | 2.65 | 1.98 |
| Turkey | 6.18 | 16.39 | 2.65 | 1.56 | 5.10 | 3.28 |
| Taiwan | 5.25 | 17.17 | 3.27 | 1.69 | 6.78 | 4.01 |
| United States | 2.90 | 7.95 | 2.74 | 0.98 | 2.39 | 2.45 |
| Rest of World | 4.51 | 14.40 | 3.19 | 1.33 | 6.74 | 5.07 |

*Notes*: The table shows the CPI and PPI elasticities to a common shock $\epsilon_m$ in the first-stage productivity, i.e., $\ln T_1'^n = \ln T_1^n + \epsilon_m, \forall n$. Columns $(1) - (3)$ are calibrated using WIOD 1998 data with $G = 2$. Columns $(4) - (6)$ are calibrated using WIOD 2005 data with $G = 4$. Under the null hypothesis that the mean of ratio in Column (6) is no larger than that in Column (3), the ratio of PPI response to CPI response in 2005 on average is significantly larger than those in 1998 with a $p$-value 0.01%.

Table 6: The correlation between the model-calibrated and empirically-estimated CPI and PPI elasticities

| | Pre-2001 period | | | | Post-2001 period | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CPI | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| Production Stages | G=2 | G=3 | G=4 | G=5 | G=2 | G=3 | G=4 | G=5 | G=6 |
| Correlation | 0.38 | 0.35 | 0.36 | 0.28 | 0.11 | 0.38 | 0.44 | 0.45 | 0.43 |
| $P$-value for the null of zero correlation | 2% | 2% | 2% | 6% | 25% | 1% | 0.3% | 0.2% | 0.3% |
| $R^2$ (%) | 14.1 | 12.3 | 13.3 | 7.6 | 1.3 | 14.5 | 19.7 | 20.3 | 18.8 |
| # Obs. | 33 | 33 | 33 | 33 | 38 | 38 | 38 | 38 | 38 |

| | Pre-2001 period | | | | Post-2001 period | | | | |
|---|---|---|---|---|---|---|---|---|---|
| PPI | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) | (18) |
| Production Stages | G=2 | G=3 | G=4 | G=5 | G=2 | G=3 | G=4 | G=5 | G=6 |
| Correlation | 0.53 | 0.43 | 0.45 | 0.35 | 0.25 | 0.27 | 0.36 | 0.34 | 0.36 |
| $P$-value for the null of zero correlation | 0.1% | 1% | 1% | 2% | 7% | 5% | 1% | 2% | 2% |
| $R^2$ (%) | 28.0 | 18.2 | 19.9 | 12.4 | 6.1 | 7.2 | 13.2 | 11.6 | 12.8 |
| # Obs. | 33 | 33 | 33 | 33 | 37 | 37 | 37 | 37 | 37 |

*Notes*: The $p$-values are for testing the null hypothesis of zero correlation (or negative correlation) between the calibrated and empirically estimated elasticities against the alternative of a positive correlation. For the post-2001 period, the empirical elasticities for Estonia (in Column 14-18), Russia and Luxembourg (in Column 5-9) appear as obvious outliers (with not only a wrong sign but also a point estimate that is much bigger in absolute value than with other countries) and are not used in the correlation calculations.

# Appendix

## A Importance of internationally traded intermediate goods

Using the data from WIOD, Appendix Figure $A.1$ presents the share of imported intermediate goods in total imported goods. We can see a clear upward trend in USA, China, Japan, Germany, 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 imported intermediate goods in total imported goods. Similar observations follow for the share of exported intermediate goods in total exported goods, as shown in Appendix Figure $A.2$.

Also by the WIOD data, Appendix Figure $A.3$ presents the share of internationally traded intermediate goods in total intermediate goods. We can also see a clear upward trend in USA, Japan, Germany, India, and the Euro Zone. 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 the 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

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

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

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

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

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

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

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

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

$$|\widehat{\ln PPI}/\widehat{\ln T_1}| = \frac{G}{\kappa} \frac{(1-\theta)\theta^{G-1}}{1-\theta^G}.$$

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

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

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

Denote $h(G) = 1 - \theta^G + G\ln\theta$. 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 the manufacturing sector, i.e., $|\widehat{\ln PPI}/\widehat{\ln T_1}| = \frac{G}{\kappa}\frac{(1-\theta)\theta^{G-1}}{1-\theta^G}$, is strictly decreasing with respect to $G$ for $\forall\theta \in (0,1)$ and $\forall G \geq 1$.

# D Proof for the monotonicity of $\widehat{\ln PPI}/\widehat{\ln CPI}$ in response to a first-stage productivity shock in the manufacturing sector

In response to a productivity shock in the manufacturing sector, the relative change of PPI over CPI satisfies the following relation:

$$\frac{\widehat{\ln PPI}}{\widehat{\ln CPI}} = \frac{(1-\theta)(G-h+1)}{\alpha(1-\theta^G)}.$$

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

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

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

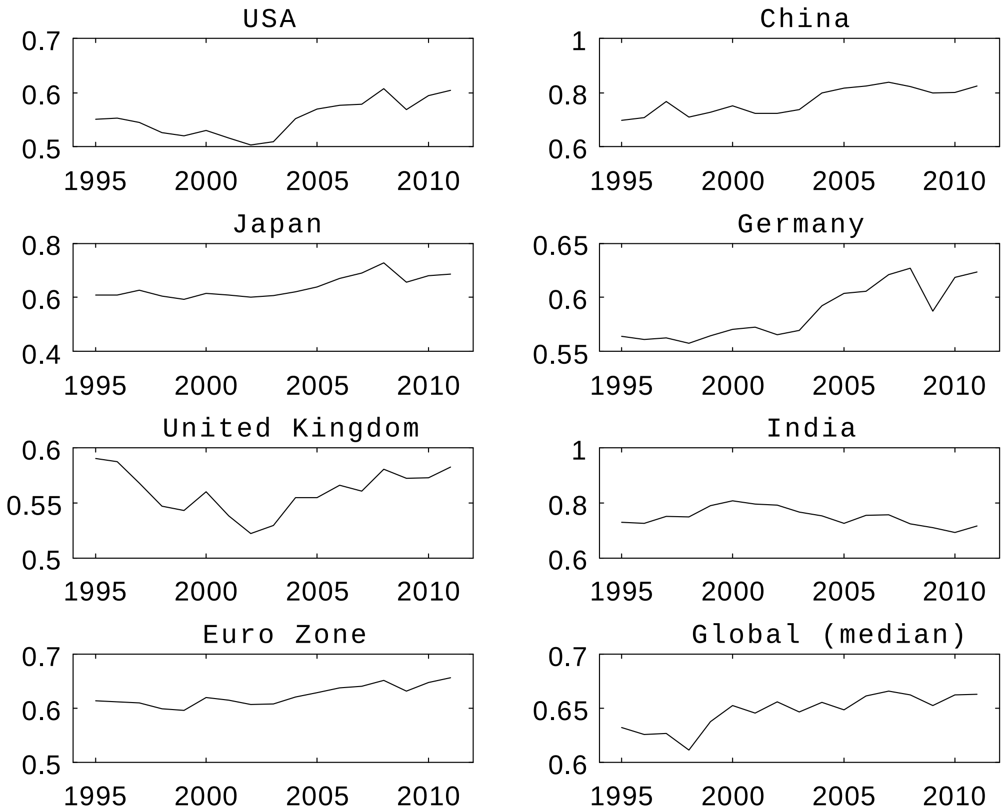
Denote $h(G) = 1 - \theta^G + G\theta^G\ln\theta$, and then we have $h' = G\theta^G(\ln\theta)^2 > 0$ and $h(1) = 1 - \theta + \theta\ln\theta$. Also, note that

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

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 $\theta \in (0,1)$, $\widehat{\ln PPI}/\widehat{\ln CPI}$ is strictly increasing in the number of total stages $G$.

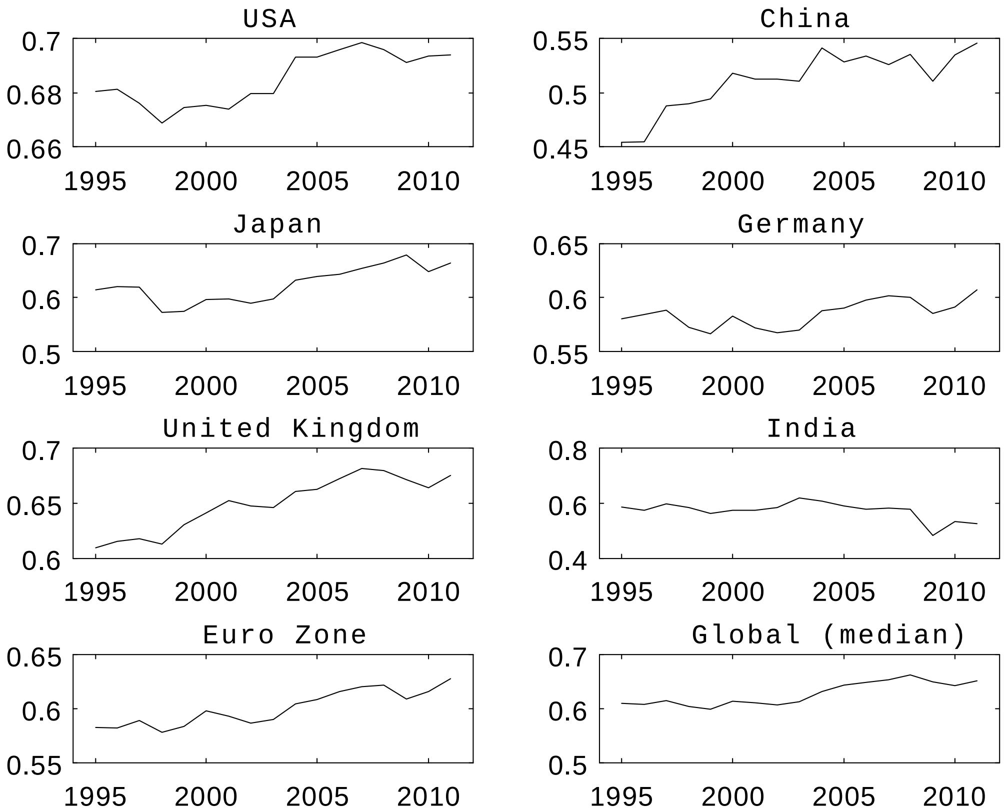
# E Empirical tests using other estimators

As a robustness check for the empirical tests in Section 6, we have conducted the same regressions by Arellano-Bond estimator and LSDV estimator. Since Arellano-Bond estimator gives almost the same results with QML estimators, we only report the results by LSDV estimator, summarized in Appendix Table $A$.9-$A$.14. The key inferences are the same as in the main text. Both CPI and PPI inflation become less responsive to a change in the industrial input price index in this century relative to the last century. The decline in the responsiveness of CPI is bigger than that of PPI. These empirical patterns are consistent with the predictions of the theoretical model.



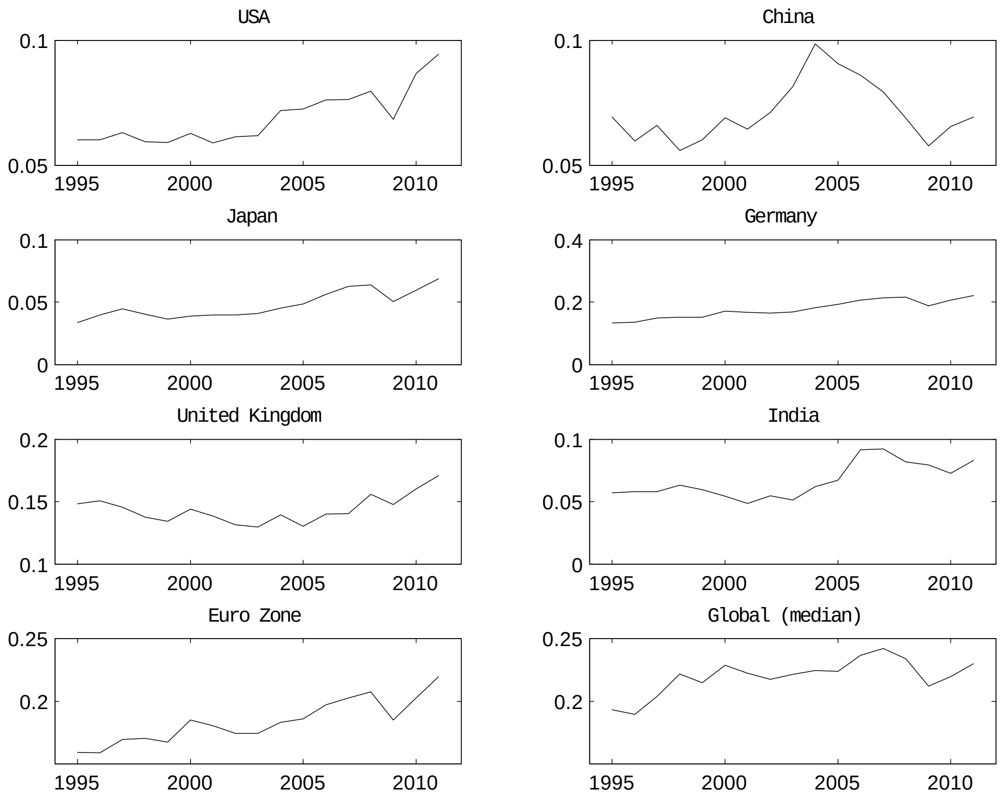

Appendix Figure A.1: Share of imported intermediate goods in total imported goods

*Notes*: This figure displays the share of imported intermediate goods in total imported goods for WIOD countries. The sub-figure labeled as "global" indicates all the countries included in the WIOD dataset.



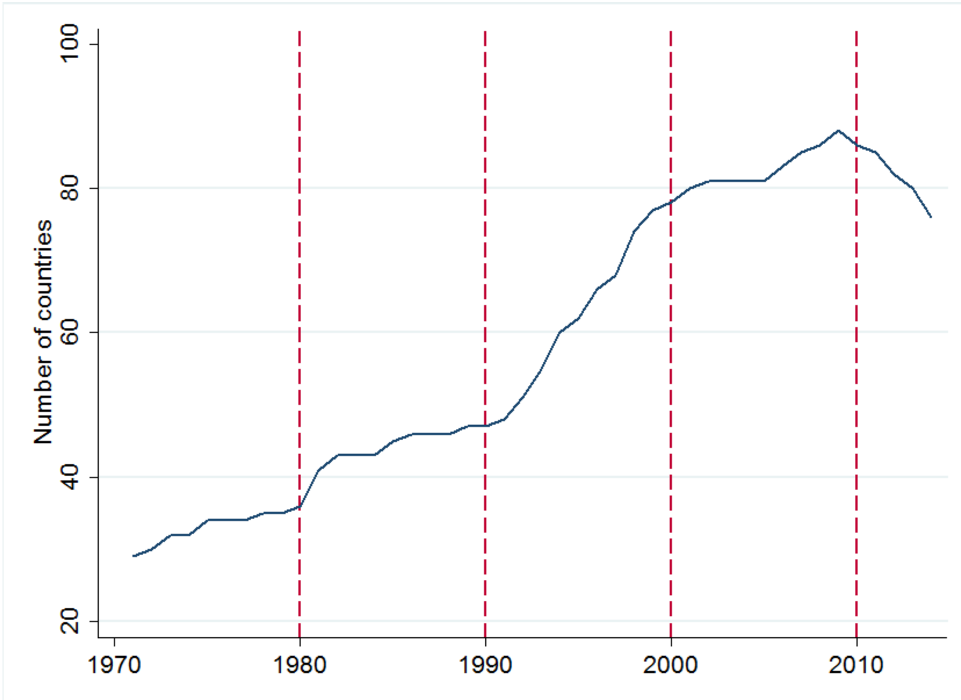

Appendix Figure A.2: Share of exported intermediate goods in total exported goods

*Notes*: This figure displays the share of exported intermediate goods in total exported goods for WIOD countries. The sub-figure labeled as "global" indicates all the countries included in the WIOD dataset.



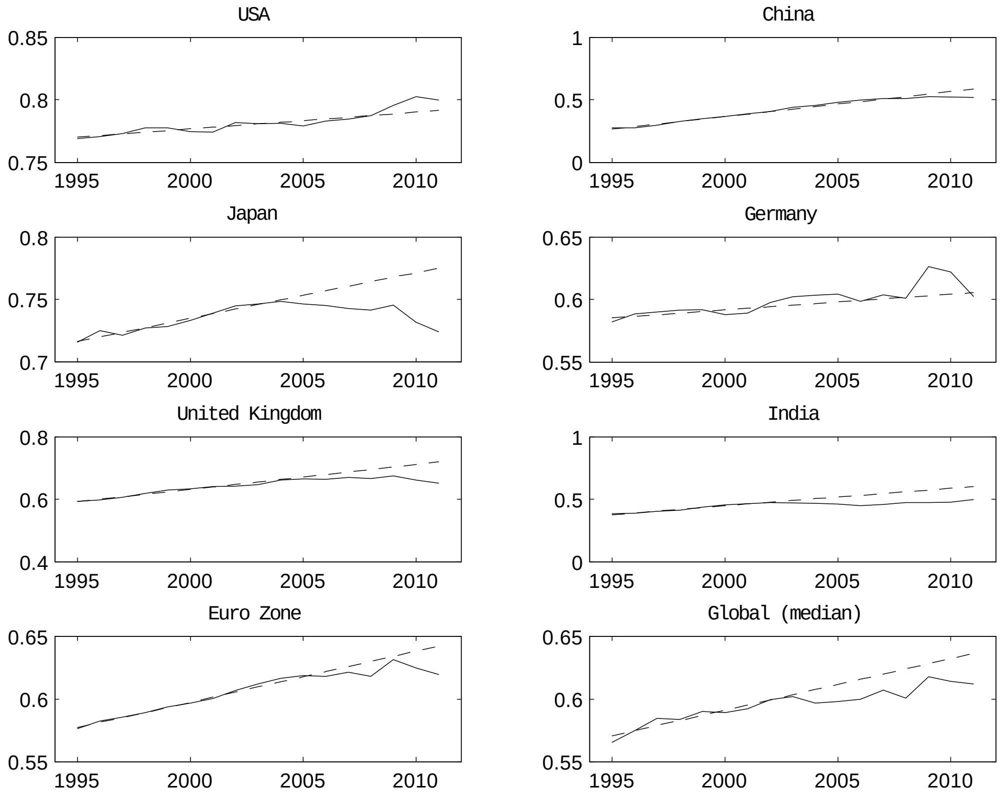

Appendix Figure A.3: Share of globally traded intermediate goods in total intermediate goods

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



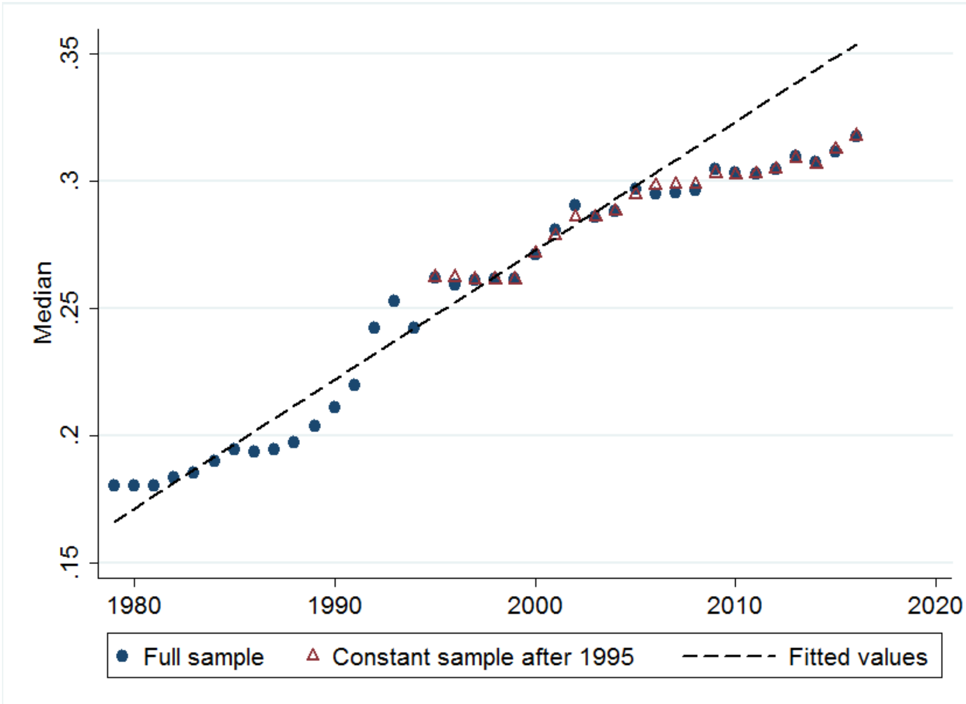

Appendix Figure A.4: The number of countries with CPI and PPI data available

*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.



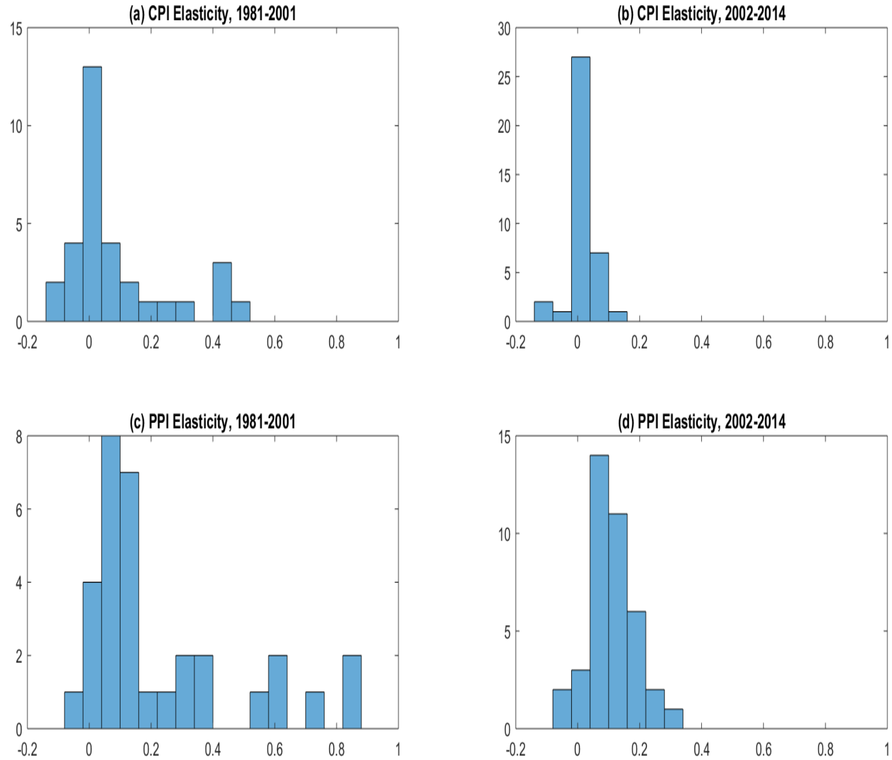

Appendix Figure A.5: Service share in household consumption, WIOD

*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 the WIOD dataset.




Appendix Figure A.6: 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 the OECD dataset). The blue dots represent the median of all countries with data available in the 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.




Appendix Figure A.7: 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.

Appendix Table A.1: 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 |
|---|---|---|---|---|---|---|
| $\Delta \ln P_{I,t}$ $(USD)$ | 0.080*** | 0.198*** | 0.026*** | 0.155*** | 0.027*** | 0.145*** |
| | (0.022) | (0.049) | (0.007) | (0.016) | (0.007) | (0.015) |
| $\Delta \ln CPI_{t-1}$ | 0.214*** | | 0.432*** | | 0.479*** | |
| | (0.044) | | (0.064) | | (0.071) | |
| $\Delta \ln PPI_{t-1}$ | | 0.047 | | 0.156*** | | 0.193*** |
| | | (0.056) | | (0.047) | | (0.048) |
| $\Delta \ln ExchangeRate_t$ | 0.491*** | 0.532*** | 0.065** | 0.189*** | 0.091** | 0.241*** |
| | (0.151) | (0.079) | (0.030) | (0.057) | (0.036) | (0.065) |
| $WageDummy * \Delta \ln wage_t$ | 0.400*** | 0.441*** | 0.188*** | 0.263*** | 0.123*** | 0.153** |
| | (0.138) | (0.091) | (0.029) | (0.079) | (0.026) | (0.068) |
| $Year2008$ | | | | | 0.051*** | 0.091*** |
| | | | | | (0.006) | (0.013) |
| $Year2009$ | | | | | -0.020** | -0.058** |
| | | | | | (0.009) | (0.024) |
| $Year2008 * \Delta \ln P_{I,t}$ $(USD)$ | | | | | 0.078 | 0.060 |
| | | | | | (0.056) | (0.098) |
| $Year2009 * \Delta \ln P_{I,t}$ $(USD)$ | | | | | 0.059 | 0.068 |
| | | | | | (0.053) | (0.190) |
| # Obs. | 1,459 | 883 | 1,407 | 1,046 | 1,407 | 1,046 |
| Ratio of Response $(R)$ | 2.475 | | 5.962 | | 5.370 | |
| $R_{post,2001} - R_{pre,2001}$ | | | 3.487 | | 2.895 | |
| $P$-value, H0 : $\Delta R \leq 0$ | | | 1.1% | | 1.6% | |

*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, $WageDummy * \Delta \ln wage_t$, equals $\Delta \ln wage_t$ 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, $Year2008 * \Delta \ln P_{Industrial,t}$, is the interaction of variable $Year2008$ and $\Delta \ln P_{Industrial,t}$. Variable, $Year2009 * \Delta \ln P_{Industrial,t}$, is the interaction of variable $Year2009$ and $\Delta \ln P_{Industrial,t}$. 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., $\frac{\partial \Delta \ln PPI_t / \partial \Delta \ln P_{Industrial,t}}{\partial \Delta \ln CPI_t / \partial \Delta \ln P_{Industrial,t}}$. Country-clustered robust standard errors are reported in parentheses. *** denotes $p < 0.01$, ** denotes $p < 0.05$, while * denotes $p < 0.1$.

Appendix Table A.2: The response of CPI and PPI inflation to commodity price

| VARIABLES | (1)<br>lnCPI<br>1993-2001 | (2)<br>lnPPI<br>1993-2001 | (3)<br>lnCPI<br>2002-2014 | (4)<br>lnPPI<br>2002-2014 | (5)<br>lnCPI<br>2002-2014 | (6)<br>lnPPI<br>2002-2014 |
|---|---|---|---|---|---|---|
| $\Delta \ln P_{Commodity,t}$ | 0.427*** | 0.694*** | 0.093*** | 0.258*** | 0.073*** | 0.240*** |
| | (0.119) | (0.140) | (0.010) | (0.029) | (0.015) | (0.035) |
| $\Delta \ln CPI_{t-1}$ | 0.319*** | | 0.605*** | | 0.575*** | |
| | (0.047) | | (0.049) | | (0.052) | |
| $\Delta \ln PPI_{t-1}$ | | 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., $\frac{\partial \Delta \ln PPI_t / \partial \Delta \ln P_{Commodity,t}}{\partial \Delta \ln CPI_t / \partial \Delta \ln P_{Commodity,t}}$. Country-clustered robust standard errors are reported in parentheses. *** denotes $p < 0.01$, ** denotes $p < 0.05$, while * denotes $p < 0.1$.

Appendix Table A.3: 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 |
|---|---|---|---|---|---|---|
| $\Delta \ln P_{C,t}$ | 0.218*** | 0.352*** | 0.091*** | 0.244*** | 0.070*** | 0.224*** |
| | (0.057) | (0.073) | (0.010) | (0.026) | (0.016) | (0.032) |
| $\Delta \ln CPI_{t-1}$ | 0.189*** | | 0.551*** | | 0.531*** | |
| | (0.056) | | (0.042) | | (0.048) | |
| $\Delta \ln PPI_{t-1}$ | | -0.027 | | 0.145*** | | 0.130*** |
| | | (0.106) | | (0.047) | | (0.046) |
| $\ln CPI_{t-1}$ | 0.189*** | | 0.551*** | | 0.531*** | |
| | (0.056) | | (0.042) | | (0.048) | |
| $\ln PPI_{t-1}$ | | -0.148*** | | -0.004 | | -0.009 |
| | | (0.050) | | (0.011) | | (0.010) |
| $WageDummy * \Delta \ln wage_t$ | 0.553*** | 0.445*** | 0.106*** | 0.127** | 0.093*** | 0.103* |
| | (0.090) | (0.131) | (0.023) | (0.060) | (0.021) | (0.059) |
| $Year2008$ | | | | | 0.041*** | 0.050*** |
| | | | | | (0.007) | (0.012) |
| $Year2009$ | | | | | 0.004 | 0.010 |
| | | | | | (0.007) | (0.020) |
| $Year2008 * \Delta \ln P_{C,t}$ | | | | | 0.126*** | 0.152* |
| | | | | | (0.049) | (0.086) |
| $Year2009 * \Delta \ln P_{C,t}$ | | | | | 0.063 | 0.093 |
| | | | | | (0.046) | (0.166) |
| # Obs. | 683 | 437 | 1,384 | 1,023 | 1,384 | 1,023 |
| Ratio of Response ($R$) | 1.615 | | 2.681 | | 3.200 | |
| $R_{post,2001} - R_{pre,2001}$ | | | 1.066 | | 1.585 | |
| $P$-value, H0 : $\Delta R \leq 0$ | | | 5.9% | | 3.9% | |

*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, $WageDummy * \Delta \ln wage_t$, equals $\Delta \ln wage_t$ 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, $Year2008 * \Delta \ln P_{Industrial,t}$, is the interaction of variable $Year2008$ and $\Delta \ln P_{Industrial,t}$. Variable, $Year2009 * \Delta \ln P_{Industrial,t}$, is the interaction of variable $Year2009$ and $\Delta \ln P_{Industrial,t}$. 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., $\frac{\partial \Delta \ln PPI_t / \partial \Delta \ln P_{Commodity,t}}{\partial \Delta \ln CPI_t / \partial \Delta \ln P_{Commodity,t}}$. Country-clustered robust standard errors are reported in parentheses. *** denotes $p < 0.01$, ** denotes $p < 0.05$, while * denotes $p < 0.1$.

Appendix Table A.4: Calibration of two-stage location parameters using 1998 data

| | Stage 1 | Stage 2 |
|---|---|---|
| Australia | 0.49 | 0.54 |
| Austria | 0.92 | 0.98 |
| Belgium | 1.10 | 1.09 |
| Bulgaria | 0.45 | 1.03 |
| Brazil | 0.97 | 1.10 |
| Canada | 0.61 | 1.14 |
| China | 0.08 | 0.81 |
| Cyprus | 1.04 | 1.19 |
| Czech Republic | 0.69 | 1.29 |
| Germany | 0.99 | 0.74 |
| Denmark | 0.59 | 0.80 |
| Spain | 0.96 | 0.57 |
| Estonia | 0.80 | 1.16 |
| Finland | 0.88 | 0.93 |
| France | 0.88 | 0.80 |
| United Kingdom | 0.77 | 1.11 |
| Greece | 0.81 | 0.95 |
| Hungary | 0.88 | 1.18 |
| India | 0.04 | 1.01 |
| Indonesia | 0.05 | 0.94 |
| Ireland | 0.96 | 1.04 |
| Italy | 1.09 | 0.79 |
| Japan | 0.98 | 0.70 |
| Korea | 0.63 | 0.85 |
| Lithuania | 1.10 | 0.89 |
| Luxembourg | 0.77 | 0.97 |
| Latvia | 0.62 | 1.21 |
| Mexico | 0.65 | 1.02 |
| Malta | 0.65 | 1.12 |
| Netherlands | 1.02 | 1.14 |
| Poland | 1.17 | 1.22 |
| Portugal | 1.04 | 1.21 |
| Romania | 1.00 | 1.05 |
| Russian Federation | 0.61 | 0.93 |
| Slovakia | 1.06 | 0.67 |
| Slovenia | 0.96 | 1.10 |
| Sweden | 0.91 | 0.96 |
| Turkey | 0.96 | 1.09 |
| Taiwan | 0.92 | 0.61 |
| United States | 1.00 | 1.00 |
| Rest of World | 0.20 | 0.58 |

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

Appendix Table A.5: Calibration of four-stage location parameters using 2005 data

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 |
|---|---|---|---|---|
| Australia | 0.83 | 0.58 | 0.48 | 0.60 |
| Austria | 1.12 | 1.01 | 0.96 | 1.19 |
| Belgium | 0.95 | 0.99 | 0.68 | 0.83 |
| Bulgaria | 1.52 | 0.98 | 0.45 | 0.84 |
| Brazil | 1.40 | 1.13 | 0.76 | 1.04 |
| Canada | 1.54 | 0.86 | 0.77 | 1.22 |
| China | 1.49 | 0.74 | 0.09 | 0.77 |
| Cyprus | 1.09 | 0.28 | 0.80 | 0.61 |
| Czech Republic | 1.39 | 0.90 | 0.93 | 0.78 |
| Germany | 1.24 | 0.80 | 0.69 | 0.93 |
| Denmark | 1.20 | 0.46 | 0.81 | 1.10 |
| Spain | 1.36 | 1.03 | 0.59 | 0.95 |
| Estonia | 1.29 | 0.58 | 0.86 | 1.01 |
| Finland | 1.13 | 0.55 | 0.64 | 0.80 |
| France | 1.29 | 1.06 | 0.82 | 0.93 |
| United Kingdom | 1.36 | 0.47 | 1.04 | 0.62 |
| Greece | 1.17 | 0.64 | 0.55 | 0.59 |
| Hungary | 0.64 | 0.70 | 0.65 | 1.01 |
| India | 1.10 | 0.96 | 0.09 | 1.10 |
| Indonesia | 1.67 | 0.74 | 0.11 | 0.48 |
| Ireland | 1.50 | 0.94 | 0.51 | 1.25 |
| Italy | 0.55 | 0.62 | 0.46 | 0.76 |
| Japan | 1.31 | 1.33 | 0.73 | 0.98 |
| Korea | 0.54 | 0.76 | 0.84 | 0.89 |
| Lithuania | 1.40 | 0.81 | 1.02 | 0.78 |
| Luxembourg | 1.26 | 0.35 | 0.78 | 0.71 |
| Latvia | 0.98 | 0.98 | 0.69 | 1.02 |
| Mexico | 1.59 | 1.03 | 0.74 | 0.74 |
| Malta | 1.10 | 1.06 | 0.59 | 0.73 |
| Netherlands | 1.26 | 0.66 | 0.45 | 0.57 |
| Poland | 1.07 | 0.67 | 0.62 | 1.04 |
| Portugal | 1.10 | 0.94 | 0.48 | 0.86 |
| Romania | 1.18 | 0.73 | 0.81 | 1.01 |
| Russian Federation | 1.48 | 0.92 | 0.56 | 1.19 |
| Slovakia | 1.24 | 1.02 | 0.57 | 1.10 |
| Slovenia | 1.27 | 0.80 | 0.79 | 0.97 |
| Sweden | 1.21 | 0.95 | 0.85 | 1.00 |
| Turkey | 1.02 | 1.08 | 0.98 | 0.87 |
| Taiwan | 0.57 | 0.88 | 0.63 | 1.14 |
| United States | 1.00 | 1.00 | 1.00 | 1.00 |
| Rest of World | 1.23 | 0.91 | 0.18 | 0.44 |

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

Appendix Table A.6: Calibration of three-stage location parameters using 2005 data

| | Stage 1 | Stage 2 | Stage 3 |
|---|---|---|---|
| Australia | 0.74 | 0.61 | 0.65 |
| Austria | 0.55 | 0.76 | 0.96 |
| Belgium | 0.88 | 0.84 | 0.90 |
| Bulgaria | 1.03 | 0.31 | 1.03 |
| Brazil | 1.26 | 0.71 | 0.99 |
| Canada | 1.27 | 1.09 | 0.93 |
| China | 0.99 | 0.15 | 0.74 |
| Cyprus | 0.84 | 1.13 | 1.04 |
| Czech Republic | 1.13 | 0.70 | 1.07 |
| Germany | 0.68 | 0.73 | 0.79 |
| Denmark | 1.18 | 0.92 | 0.91 |
| Spain | 0.91 | 0.91 | 0.87 |
| Estonia | 0.74 | 0.96 | 1.12 |
| Finland | 0.96 | 0.41 | 0.44 |
| France | 1.07 | 0.99 | 0.74 |
| United Kingdom | 1.29 | 0.78 | 0.84 |
| Greece | 0.84 | 0.57 | 1.13 |
| Hungary | 0.67 | 1.05 | 0.96 |
| India | 0.24 | 0.88 | 0.51 |
| Indonesia | 1.16 | 0.06 | 0.87 |
| Ireland | 1.20 | 0.95 | 1.02 |
| Italy | 1.00 | 0.95 | 0.92 |
| Japan | 0.77 | 0.87 | 0.82 |
| Korea | 1.01 | 0.86 | 1.15 |
| Lithuania | 0.96 | 0.70 | 0.95 |
| Luxembourg | 1.34 | 1.02 | 0.85 |
| Latvia | 1.27 | 1.00 | 1.05 |
| Mexico | 1.27 | 1.17 | 0.73 |
| Malta | 0.62 | 0.92 | 0.82 |
| Netherlands | 1.02 | 0.80 | 0.74 |
| Poland | 0.63 | 1.08 | 0.76 |
| Portugal | 0.54 | 0.80 | 0.75 |
| Romania | 1.35 | 0.74 | 0.95 |
| Russian Federation | 0.97 | 0.66 | 1.18 |
| Slovakia | 1.14 | 0.87 | 1.11 |
| Slovenia | 0.98 | 0.73 | 0.82 |
| Sweden | 0.74 | 0.81 | 0.73 |
| Turkey | 1.07 | 0.86 | 0.59 |
| Taiwan | 1.17 | 1.08 | 1.01 |
| United States | 1.00 | 1.00 | 1.00 |
| Rest of World | 1.24 | 0.24 | 0.44 |

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

Appendix Table A.7: The elasticities of CPI and PPI inflation 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) | (5) | (6) |
| | $\Delta \ln CPI(\%)$ | $\Delta \ln PPI(\%)$ | $\frac{\Delta \ln PPI}{\Delta \ln CPI}$ | $\Delta \ln CPI(\%)$ | $\Delta \ln PPI(\%)$ | $\frac{\Delta \ln PPI}{\Delta \ln CPI}$ |
| Australia | 4.79 | 9.53 | 1.99 | 2.58 | 4.56 | 1.77 |
| Austria | 4.84 | 9.31 | 1.92 | 2.32 | 4.87 | 2.10 |
| Belgium | 5.08 | 9.62 | 1.90 | 2.60 | 5.11 | 1.96 |
| Bulgaria | 8.08 | 17.81 | 2.20 | 3.00 | 9.01 | 3.01 |
| Brazil | 4.08 | 15.05 | 3.69 | 2.43 | 8.85 | 3.65 |
| Canada | 4.22 | 9.29 | 2.20 | 2.55 | 5.42 | 2.12 |
| China | 10.62 | 18.96 | 1.78 | 5.38 | 15.31 | 2.85 |
| Cyprus | 4.51 | 9.72 | 2.16 | 1.92 | 4.51 | 2.35 |
| Czech Republic | 7.16 | 14.57 | 2.04 | 3.19 | 7.92 | 2.48 |
| Germany | 5.02 | 10.20 | 2.03 | 2.57 | 5.07 | 1.97 |
| Denmark | 4.36 | 7.88 | 1.81 | 2.25 | 3.90 | 1.73 |
| Spain | 5.03 | 13.30 | 2.65 | 2.48 | 7.33 | 2.95 |
| Estonia | 5.38 | 14.55 | 2.70 | 2.03 | 5.92 | 2.92 |
| Finland | 3.85 | 11.31 | 2.94 | 2.05 | 5.80 | 2.83 |
| France | 5.29 | 9.15 | 1.73 | 2.63 | 5.15 | 1.96 |
| United Kingdom | 4.81 | 7.78 | 1.62 | 2.37 | 3.35 | 1.42 |
| Greece | 4.76 | 10.18 | 2.14 | 2.12 | 4.21 | 1.98 |
| Hungary | 7.10 | 16.67 | 2.35 | 3.02 | 8.09 | 2.68 |
| India | 7.27 | 16.95 | 2.33 | 3.12 | 9.76 | 3.12 |
| Indonesia | 8.23 | 17.35 | 2.11 | 4.14 | 13.79 | 3.33 |
| Ireland | 5.15 | 10.02 | 1.94 | 2.39 | 4.40 | 1.84 |
| Italy | 5.75 | 10.49 | 1.82 | 2.81 | 4.91 | 1.75 |
| Japan | 3.63 | 11.13 | 3.06 | 2.05 | 6.70 | 3.27 |
| Korea | 4.69 | 17.20 | 3.67 | 2.69 | 11.54 | 4.29 |
| Lithuania | 7.37 | 18.50 | 2.51 | 3.31 | 7.51 | 2.27 |
| Luxembourg | 5.04 | 4.83 | 0.96 | 2.44 | 1.42 | 0.58 |
| Latvia | 5.42 | 14.17 | 2.61 | 1.83 | 6.97 | 3.80 |
| Mexico | 5.38 | 17.50 | 3.25 | 2.77 | 9.56 | 3.45 |
| Malta | 6.51 | 15.72 | 2.41 | 2.72 | 5.26 | 1.93 |
| Netherlands | 4.61 | 9.29 | 2.02 | 2.31 | 4.81 | 2.09 |
| Poland | 5.90 | 15.60 | 2.65 | 2.36 | 7.26 | 3.07 |
| Portugal | 5.25 | 14.49 | 2.76 | 2.54 | 6.49 | 2.55 |
| Romania | 8.42 | 18.08 | 2.15 | 3.40 | 9.80 | 2.88 |
| Russian Federation | 6.43 | 16.07 | 2.50 | 2.70 | 7.42 | 2.75 |
| Slovakia | 6.27 | 20.93 | 3.34 | 3.42 | 9.30 | 2.72 |
| Slovenia | 6.22 | 13.77 | 2.21 | 2.65 | 7.79 | 2.94 |
| Sweden | 4.22 | 8.96 | 2.12 | 2.45 | 4.75 | 1.94 |
| Turkey | 6.18 | 16.39 | 2.65 | 2.89 | 8.47 | 2.93 |
| Taiwan | 5.25 | 17.17 | 3.27 | 2.74 | 11.25 | 4.10 |
| United States | 2.90 | 7.95 | 2.74 | 1.70 | 3.82 | 2.25 |
| Rest of World | 4.51 | 14.40 | 3.19 | 2.46 | 12.03 | 4.90 |

*Notes*: The table shows the CPI and PPI elasticities to a common shock $\epsilon_m$ in the first-stage productivity, i.e., $\ln T_1'^n = \ln T_1^n + \epsilon_m, \forall n$. Columns $(1)-(3)$ are calibrated using WIOD 1998 data with $G = 2$. Columns $(4)-(6)$ are calibrated using WIOD 2005 data with $G = 3$. Under the null hypothesis that the mean of ratio in Column (6) is no larger than that in Column (3), the ratio of PPI response to CPI response in 2005 on average is significantly larger than those in 1998 with a $p$-value 0.4%.

Appendix Table A.8: The correlation between the calibrated and empirically estimated CPI and PPI elasticities using 1997 and 2006 WIOD data

| | The pre-2001 period | | | | The post-2001 period | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CPI | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| Production Stages | G=2 | G=3 | G=4 | G=5 | G=2 | G=3 | G=4 | G=5 | G=6 |
| Correlation | 0.45 | 0.40 | 0.40 | 0.39 | 0.12 | 0.31 | 0.40 | 0.49 | 0.50 |
| $P$-value for the null of zero correlation | 1% | 1% | 1% | 1% | 23% | 3% | 1% | 0.1% | 0.1% |
| $R^2$ (%) | 19.9 | 16.2 | 15.9 | 15.3 | 1.5 | 9.4 | 16.1 | 24.1 | 25.4 |
| # Obs. | 33 | 33 | 33 | 33 | 38 | 38 | 38 | 38 | 38 |

| | The pre-2001 period | | | | The post-2001 period | | | | |
|---|---|---|---|---|---|---|---|---|---|
| PPI | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) | (18) |
| Production Stages | G=2 | G=3 | G=4 | G=5 | G=2 | G=3 | G=4 | G=5 | G=6 |
| Correlation | 0.46 | 0.52 | 0.50 | 0.43 | 0.14 | 0.24 | 0.25 | 0.27 | 0.32 |
| $P$-value for the null of zero correlation | 0.4% | 0.1% | 0.2% | 1% | 20% | 8% | 7% | 6% | 2% |
| $R^2$ (%) | 20.8 | 26.9 | 24.6 | 18.6 | 2.0 | 5.6 | 6.2 | 7.1 | 10.3 |
| # Obs. | 33 | 33 | 33 | 33 | 37 | 37 | 37 | 37 | 37 |

*Notes*: The $p$-values are for testing the null hypothesis of zero correlation (or negative correlation) between the calibrated and empirically estimated elasticities against the alternative of a positive correlation. For the post-2001 period, the empirical elasticities for Estonia (in Column 14-18), and Russia and Luxembourg (in Column 5-9) appear as obvious outliers (with not only a wrong sign but also a point estimate that is much bigger in absolute value than with other countries) and are not used in the correlation calculations.

Appendix Table A.9: The response of CPI and PPI inflation to industrial input price

| VARIABLES | (1)<br>lnCPI<br>1981-2001 | (2)<br>lnPPI<br>1981-2001 | (3)<br>lnCPI<br>2002-2014 | (4)<br>lnPPI<br>2002-2014 | (5)<br>lnCPI<br>2002-2014 | (6)<br>lnPPI<br>2002-2014 |
|---|---|---|---|---|---|---|
| $\Delta \ln P_{Industrial,t}$ | 0.533*** | 0.749*** | 0.029*** | 0.142*** | 0.040*** | 0.156*** |
| | (0.104) | (0.095) | (0.009) | (0.019) | (0.010) | (0.022) |
| $\Delta \ln CPI_{t-1}$ | 0.329*** | | 0.373*** | | 0.415*** | |
| | (0.056) | | (0.057) | | (0.062) | |
| $\Delta \ln PPI_{t-1}$ | | 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., $\frac{\partial \Delta \ln PPI_t / \partial \Delta \ln P_{Industrial,t}}{\partial \Delta \ln CPI_t / \partial \Delta \ln P_{Industrial,t}}$. 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 $p < 0.1$.

Appendix Table A.10: The response of CPI and PPI inflation to industrial input price with controlling nominal wage

| VARIABLES | (1)<br>lnCPI<br>1981-2001 | (2)<br>lnPPI<br>1981-2001 | (3)<br>lnCPI<br>2002-2014 | (4)<br>lnPPI<br>2002-2014 | (5)<br>lnCPI<br>2002-2014 | (6)<br>lnPPI<br>2002-2014 |
|---|---|---|---|---|---|---|
| $\Delta \ln P_{Industrial,t}$ | 0.408*** | 0.553*** | 0.026*** | 0.139*** | 0.039*** | 0.155*** |
| | (0.123) | (0.094) | (0.009) | (0.020) | (0.010) | (0.023) |
| $\Delta \ln CPI_{t-1}$ | 0.255*** | | 0.348*** | | 0.395*** | |
| | (0.045) | | (0.051) | | (0.058) | |
| $\Delta \ln PPI_{t-1}$ | | 0.115 | | 0.047 | | 0.115** |
| | | (0.084) | | (0.048) | | (0.048) |
| $WageDummy * \Delta \ln wage_t$ | 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, $WageDummy * \Delta \ln wage_t$, equals $\Delta \ln wage_t$ 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., $\frac{\partial \Delta \ln PPI_t / \partial \Delta \ln P_{Industrial,t}}{\partial \Delta \ln CPI_t / \partial \Delta \ln P_{Industrial,t}}$. 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 $p < 0.1$.

Appendix Table A.11: 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 |
|---|---|---|---|---|---|---|
| $\Delta \ln P_{I,t}$ | 0.389*** | 0.537*** | 0.025*** | 0.121*** | 0.034*** | 0.135*** |
| | (0.117) | (0.095) | (0.009) | (0.016) | (0.010) | (0.019) |
| $\Delta \ln CPI_{t-1}$ | 0.253*** | | 0.347*** | | 0.394*** | |
| | (0.041) | | (0.053) | | (0.060) | |
| $\Delta \ln PPI_{t-1}$ | | 0.118 | | 0.046 | | 0.110** |
| | | (0.083) | | (0.043) | | (0.043) |
| $\ln CPI_{t-1}$ | -0.017*** | | -0.005 | | -0.003 | |
| | (0.005) | | (0.008) | | (0.008) | |
| $\ln PPI_{t-1}$ | | -0.010* | | -0.053*** | | -0.045*** |
| | | (0.005) | | (0.013) | | (0.012) |
| $WageDummy * \Delta \ln wage_t$ | 0.422*** | 0.353*** | 0.179*** | 0.191** | 0.119*** | 0.071 |
| | (0.114) | (0.107) | (0.035) | (0.077) | (0.030) | (0.067) |
| $Year2008$ | | | | | 0.055*** | 0.097*** |
| | | | | | (0.006) | (0.014) |
| $Year2009$ | | | | | -0.001 | -0.027 |
| | | | | | (0.006) | (0.022) |
| $Year2008 * \Delta lnP_{I,t}$ | | | | | 0.124*** | 0.141* |
| | | | | | (0.046) | (0.084) |
| $Year2009 * \Delta lnP_{I,t}$ | | | | | 0.122*** | 0.176 |
| | | | | | (0.041) | (0.183) |
| 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 | | 3.971 | |
| $R_{post,2001} - R_{pre,2001}$ | | | 3.460 | | 2.591 | |
| $P$-value, H0 : $\Delta R \leq 0$ | | | 1.3% | | 2.4% | |

*Notes*: This table estimates the responses of CPI and PPI inflation to changes in industrial input prices. The LSDV estimators are adopted. Variable, $WageDummy * \Delta \ln wage_t$, equals $\Delta \ln wage_t$ 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, $Year2008 * \Delta \ln P_{Industrial,t}$, is the interaction of variable $Year2008$ and $\Delta \ln P_{Industrial,t}$. Variable, $Year2009 * \Delta \ln P_{Industrial,t}$, is the interaction of variable $Year2009$ and $\Delta \ln P_{Industrial,t}$. 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., $\frac{\partial \Delta \ln PPI_t / \partial \Delta \ln P_{Industrial,t}}{\partial \Delta \ln CPI_t / \partial \Delta \ln P_{Industrial,t}}$. 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 $p < 0.1$.

Appendix Table A.12: 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 |
|---|---|---|---|---|---|---|
| $\Delta \ln P_{I,t}$ $(USD)$ | 0.061*** | 0.214*** | 0.021*** | 0.135*** | 0.024*** | 0.133*** |
| | (0.021) | (0.053) | (0.007) | (0.015) | (0.007) | (0.015) |
| $\Delta \ln CPI_{t-1}$ | 0.236*** | | 0.340*** | | 0.395*** | |
| | (0.046) | | (0.049) | | (0.055) | |
| $\Delta \ln PPI_{t-1}$ | | 0.095 | | 0.043 | | 0.106** |
| | | (0.073) | | (0.046) | | (0.046) |
| $\Delta \ln ExchangeRate_t$ | 0.488*** | 0.684*** | 0.062** | 0.156*** | 0.087** | 0.208*** |
| | (0.133) | (0.091) | (0.031) | (0.059) | (0.037) | (0.069) |
| $WageDummy * \Delta \ln wage_t$ | 0.386*** | 0.257** | 0.197*** | 0.219** | 0.132*** | 0.106 |
| | (0.112) | (0.102) | (0.033) | (0.088) | (0.029) | (0.075) |
| $Year2008$ | | | | | 0.050*** | 0.093*** |
| | | | | | (0.007) | (0.015) |
| $Year2009$ | | | | | -0.015 | -0.046* |
| | | | | | (0.009) | (0.026) |
| $Year2008 * \Delta lnP_{I,t}$ | | | | | 0.077 | 0.094 |
| | | | | | (0.059) | (0.107) |
| $Year2009 * \Delta lnP_{I,t}$ | | | | | 0.070 | 0.114 |
| | | | | | (0.053) | (0.198) |
| # 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 | | 5.442 | |
| $R_{post,2001} - R_{pre,2001}$ | | | 2.921 | | 2.484 | |
| $P$-value, H0 : $\Delta R \leq 0$ | | | 7.7% | | 12.5% | |

*Notes*: This table estimates the responses of CPI and PPI inflation to changes in industrial input prices. The LSDV estimators are adopted. Variable, $WageDummy * \Delta \ln wage_t$, equals $\Delta \ln wage_t$ 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, $Year2008 * \Delta \ln P_{Industrial,t}$, is the interaction of variable $Year2008$ and $\Delta \ln P_{Industrial,t}$. Variable, $Year2009 * \Delta \ln P_{Industrial,t}$, is the interaction of variable $Year2009$ and $\Delta \ln P_{Industrial,t}$. 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., $\frac{\partial \Delta \ln PPI_t / \partial \Delta \ln P_{Industrial,t}}{\partial \Delta \ln CPI_t / \partial \Delta \ln P_{Industrial,t}}$. 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 $p < 0.1$.

Appendix Table A.13: The response of CPI and PPI inflation to commodity price

| VARIABLES | (1)<br>$\Delta lnCPI$<br>1993-2001 | (2)<br>$\Delta lnPPI$<br>1993-2001 | (3)<br>$\Delta lnCPI$<br>2002-2014 | (4)<br>$\Delta lnPPI$<br>2002-2014 | (5)<br>$\Delta lnCPI$<br>2002-2014 | (6)<br>$\Delta lnPPI$<br>2002-2014 |
|---|---|---|---|---|---|---|
| $\Delta \ln P_{Commodity,t}$ | 0.439*** | 0.772*** | 0.086*** | 0.246*** | 0.070*** | 0.232*** |
| | (0.134) | (0.133) | (0.010) | (0.029) | (0.016) | (0.036) |
| $\Delta \ln CPI_{t-1}$ | 0.350*** | | 0.480*** | | 0.464*** | |
| | (0.050) | | (0.044) | | (0.049) | |
| $\Delta \ln PPI_{t-1}$ | | 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., $\frac{\partial \Delta \ln PPI_t / \partial \Delta \ln P_{Commodity,t}}{\partial \Delta \ln CPI_t / \partial \Delta \ln P_{Commodity,t}}$. 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 $p < 0.1$.

Appendix Table A.14: 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 |
|---|---|---|---|---|---|---|
| $\Delta \ln P_{C,t}$ | 0.262*** | 0.562*** | 0.083*** | 0.231*** | 0.063*** | 0.211*** |
| | (0.100) | (0.111) | (0.010) | (0.027) | (0.016) | (0.033) |
| $\Delta \ln CPI_{t-1}$ | 0.239*** | | 0.459*** | | 0.443*** | |
| | (0.046) | | (0.042) | | (0.048) | |
| $\Delta \ln PPI_{t-1}$ | | 0.117* | | 0.081* | | 0.069 |
| | | (0.068) | | (0.043) | | (0.043) |
| $\ln CPI_{t-1}$ | -0.085*** | | 0.002 | | -0.001 | |
| | (0.024) | | (0.006) | | (0.007) | |
| $\ln PPI_{t-1}$ | | -0.097*** | | -0.028** | | -0.031*** |
| | | (0.027) | | (0.011) | | (0.011) |
| $WageDummy * \Delta \ln wage_t$ | 0.427*** | 0.228** | 0.126*** | 0.108 | 0.107*** | 0.090 |
| | (0.121) | (0.107) | (0.032) | (0.070) | (0.029) | (0.069) |
| $Year2008$ | | | | | 0.040*** | 0.047*** |
| | | | | | (0.007) | (0.012) |
| $Year2009$ | | | | | 0.008 | 0.011 |
| | | | | | (0.007) | (0.022) |
| $Year2008 * \Delta lnP_{C,t}$ | | | | | 0.105** | 0.084 |
| | | | | | (0.048) | (0.085) |
| $Year2009 * \Delta lnP_{C,t}$ | | | | | 0.087* | 0.086 |
| | | | | | (0.045) | (0.180) |
| 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 | | 3.350 | |
| $R_{post,2001} - R_{pre,2001}$ | | | 0.638 | | 1.204 | |
| $P$-value, H0 : $\Delta R \leq 0$ | | | 24.4% | | 17.4% | |

*Notes*: This table estimates the responses of CPI and PPI inflation to changes in commodity prices. The LSDV estimators are adopted. Variable, $WageDummy * \Delta \ln wage_t$, equals $\Delta \ln wage_t$ 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, $Year2008 * \Delta \ln P_{Industrial,t}$, is the interaction of variable $Year2008$ and $\Delta \ln P_{Industrial,t}$. Variable, $Year2009 * \Delta lnP_{Industrial,t}$, is the interaction of variable $Year2009$ and $\Delta \ln P_{Industrial,t}$. 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., $\frac{\partial \Delta \ln PPI_t / \partial \Delta \ln P_{Commodity,t}}{\partial \Delta \ln CPI_t / \partial \Delta \ln P_{Commodity,t}}$. 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 $p < 0.1$.