The Supply-Side Origins of U.S. Inflation

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Pages 227-268 | Chapter printout

Changing Inflation Dynamics, Evolving Monetary Policy

Gonzalo Castex, Jordi Galí, and Diego Saravia
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In recent years, we have not seen much of a negative correlation between inflation, the time series plotted in figure 1, and measures of resource slack, based on real GDP plotted in figure 2. This flattening of the Phillips curve in many countries across the world has startled monetary policymakers. In fact, it has some former policymakers ask whether the Phillips curve is dead.[1] It is often interpreted as the disappearance of a short-run output-inflation tradeoff that central banks can exploit for stabilization purposes.[2]

In this paper I argue that this is too pessimistic an assessment. What the flattening of the Phillips curve really indicates is that recent economic fluctuations were not mainly driven by movements in aggregate demand (AD) but, instead, by joint movements in aggregate demand and aggregate supply (AS). It is these movements in aggregate supply that are at the root of the "supply-side origins of inflation" that I refer to in the title.

In the first part of this paper, I illustrate that, once one is willing to drop the assumption in a textbook aggregate demand-aggregate supply (AD-AS) framework that business-cycle fluctuations are mainly the result of movements in aggregate demand, it is not hard to imagine how joint inward shifts in both aggregate demand and aggregate supply can result in economic downturns without much of a, if any, decline in inflation. I discuss how a broad range of recent papers and explanations

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1. See Blinder (2018).

2. The potential for such an output-inflation tradeoff was first emphasized in Samuelson and Solow (1960)'s reinterpretation of Phillips (1958).

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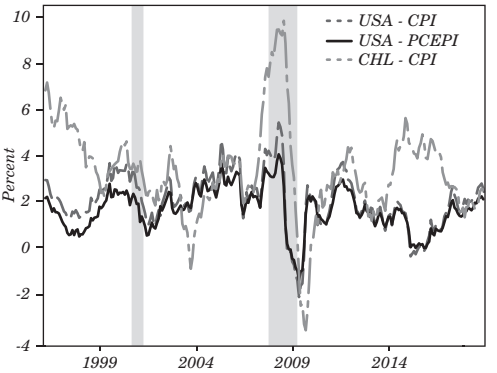
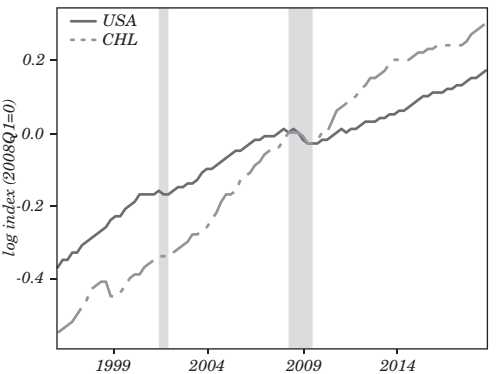
can be interpreted as shifts in the short-run aggregate supply (SRAS) curve that is the backbone of the upward-sloping Phillips curve.[3]

Figure 1. Inflation Rates in U.S. and Chile: 1996-2018



Sources: Bureau of Labor Statistics (BLS), Bureau of Economic Analysis (BEA), and Organization of Economic Cooperation and Development(OECD).
Note: 12-month inflation rates. Shading shows U.S. recessions.

Figure 2. Log Real GDP in U.S. and Chile: 1996-2018



Sources: BEA and OECD.
Note: Log index 2008Q1=0. Shading shows U.S. recessions.

3. This includes Ravenna and Walsh (2006), Gilchrist and others (2017), Daly and Hobijn (2014), and Carlstrom and others (2017) among many.

Looking at the flattening of the Phillips curve through this joint AD-AS shift lens reveals some important insights. First of all, it implies that the flattening of the Phillips curve is not indicative of the absence of a transmission of monetary policy to the real economy. Instead, it suggests this transmission works through both the AD and the SRAS curves. Secondly, as a consequence of this first insight, this means that monetary policymakers have to think beyond the common focus on keeping "the growth of aggregate demand stable in order to prevent fluctuations in real output and inflation."[4] Finally, thinking beyond this common focus involves identifying and quantifying the supply-side effects of monetary policy and their impact on output and, most importantly for the second part of this paper, inflation.

In order to study the supply-side effects of monetary policy and their impact on inflation, we need to be able to measure how important supply-side factors, like factor costs, technology, and markups, are for inflation. One way would be to use a New Keynesian (NK) dynamic stochastic general equilibrium (DSGE) model.

But it is exactly that type of model that has not been particularly satisfactory in furthering our understanding of recent inflation dynamics. This is the reason I explore a different approach in this paper. Namely, to apply growth-accounting techniques that are generally used for the medium- to long-run analysis of the supply side of the economy for decomposing the sources of inflation.

In the second part of the paper I present the results obtained with this approach. I use dual growth-accounting methods to quantify the supply-side factors that underlie inflation in the headline personal consumption expenditures (PCE) price index[5] in the U.S. from 1999 to 2015.

The value chain of the PCE goods and services, whose price changes are captured in personal consumption expenditures price index (PCEPI) inflation, has not changed a lot from 1999 to 2015. The relative contributions of domestic industries to the cost of these goods has remained approximately constant over time. What has changed is the importance of imports and where they flow into the supply chain.

4. See Taylor (1997).
5. This is the price index that the Federal Reserve explicitly targets.

Since 1998 the share of the cost of PCE traceable to imports has increased from 7.6 percent on the dollar to 10.6 percent. This share peaked in 2008. Imports increasingly flow into the U.S. supply chain at more advanced stages of production. In terms of the production factors that contribute to these costs, the share of labor has declined steadily. This largely reflects the decline in the factor requirement of unskilled labor over time.

Import-price fluctuations played an outsized role in the dynamics of PCEPI inflation in the U.S. Even though imports only account for a tenth of the cost of PCE spending, import-price movements account for 45 percent of the variance in inflation. The contributions of changes in the costs of capital and total factor productivity (TFP) growth to inflation largely offset each other. This is possibly due to movements in markups that the dual growth-accounting method I use does not explicitly take into account. Labor compensation, even though it makes up half of the cost of PCE spending, accounts for less than a fifth of inflation fluctuations.

The data requirements for the dual growth-accounting methods I use are steep and the relevant data is released with a substantial delay. However, the contributions of import-price inflation, measured TFP growth, and, to a lesser extent, labor, can be reasonably approximated by using simple rules of thumb that can be implemented almost in real time.

The results in this paper show how the application of growth-accounting methods, normally used to analyze long-run growth and productivity trends, to short-run movements in inflation uncovers useful facts about the supply-side origins of inflation. These growth-accounting methods are based on neoclassical assumptions and do not, yet, allow for disentangling markups. Neither are they applicable in many countries other than the U.S. due to a lack of data. These are two areas that central banks possibly can contribute to with their research and resources.

1. Beyond Demand-Driven Inflation Fluctuations

To understand what I mean by the "supply-side origins" of inflation, it is useful to start with the textbook explanation of the AD-AS model. Though such a textbook-type exposition definitely does not do justice to the numerous academic studies that employ the three-equation NK model and variations and extensions thereof, it does capture the main

intuition of many of the core principles that leading macroeconomists agreed on in 1997.[6,7]

The textbook explanation is illustrated in panel (i) of figure 3. The diagram in this panel can be understood in terms of the core principles laid out in 1997. First, the short-run aggregate supply curve in the panel captures that "there is a short-run tradeoff between inflation and unemployment".[8] Second, the shifts in the aggregate demand curve reflect the commonly-held belief that most fluctuations of output around its long-run trend "...are predominantly driven by aggregate demand impulses".[9] The latter is the equivalent of an identifying assumption in an instrumental variables (IV) regression.

In its purest form, plotted here, this implies that business-cycle fluctuations only shift the AD curve and are orthogonal to shifts in the SRAS curve. As a result, business-cycle fluctuations (to the extent they are not dampened by stabilization policies) result in shifts of the AD curve along the (fixed) SRAS curve. Thus, under this identifying assumption, business-cycle fluctuations allow for the identification of the slope of the SRAS curve, i.e., the sacrifice ratio.

If AD fluctuations are the (main) driver of business cycles, then the focus of stabilization policies should be to "...keep the growth of aggregate demand stable in order to prevent fluctuations in real output and inflation."[10] Though not easy to implement in practice, this is a remarkably simple conceptual description of optimal stabilization policies, including monetary policy.

The problem is that, in recent years, the empirical Phillips curve that such AD fluctuations imply is not in, or hard to extract from, the data.[11] The reason I emphasized the IV interpretation of the identifying assumptions underlying the Phillips curve above is that it provides us with a way to think through why we are not retrieving a positive correlation between output and inflation from the data.

6. See Blanchard (1997), Blinder (1997), Eichenbaum (1997), Solow (1997), and Taylor (1997).

7. The version of the AD-AS model that I plot here has the inflation rate on the vertical axis, rather than the price level. This is to bring the exposition more in line in with NK models.

8. See Taylor (1997).

9. See Solow (1997).

10. Taylor (1997).

11. It is important to realize that the Phillips curve implied by panel (i) of figure 3 is a simplification. Most empirical Phillips curve relationships include long lags. Moreover, even historically, the empirical Phillips curve worked well and was relatively stable only in the United States. (Blinder, 1997).

Within this textbook framework, there are three reasons why we could observe a flat Phillips curve. The first two maintain that business-cycle fluctuations are mainly driven by demand shocks. In that case, the SRAS curve can have flattened. Thus, firms' price-setting decisions depend less on the current level of economic activity. In a conventional three-equation NK model this could, for example, happen if there is an increase in nominal rigidities (especially price rigidities). Empirical studies using micro-price data do not reveal such an increase.

Another possibility would be that the AD curve has flattened. For example, a country where the central bank is hawkish on inflation will have a flatter AD curve than a country with a more dovish central bank. Of course, in this very simple stylized framework, a flat AD curve means that demand shocks do not affect the level of real activity, i.e., output, in the economy. Thus, in this simple diagram output fluctuations cannot be demand driven when the AD curve is flat. Though this is an artifact of the simple framework I use here, it does bring me to the third possible reason that the empirical Phillips curve has not been stable in recent years.

This third reason is what is plotted in panel (ii) of figure 3. It is that economic fluctuations in recent years have been driven by positively correlated demand and supply shocks of similar magnitude. That is, the sources of recent economic fluctuations violate the IV identifying restriction that allows us to recover the sacrifice ratio. That is, declines in demand, like during the Great Recession and its aftermath, were accompanied by shifts in the SRAS curve. As a result, the downward pressures on inflation from the AD shifts are offset by the upward pressures on inflation resulting from the shift in the SRAS curve. Panel (ii) of figure 3 illustrates the case in which the correlated shocks fully offset each other in terms of inflation.

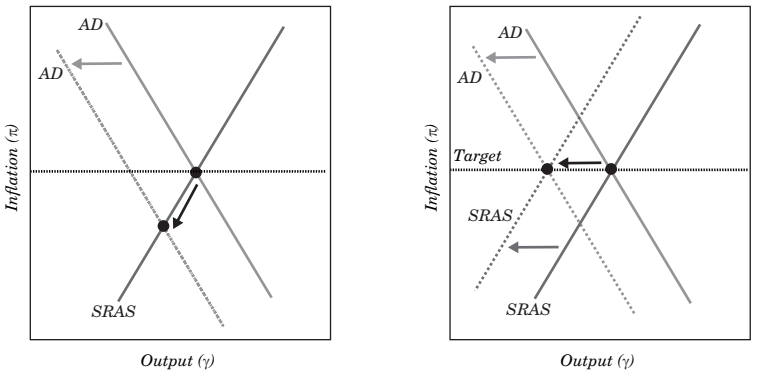
The textbook AD-AS framework that I use to illustrate my point in figure 3 might seem rather simplistic. However, the main insight translates directly to a standard three-equation NK model. In fact, figure 4 plots the NK Phillips curve, i.e., the relationship between the percent deviation of output and inflation from their steady-state values in two cases.

The case in the left panel is the one that satisfies the conventional assumption that short-run economic fluctuations are due to demand shocks. Demand shocks in the context of this model reflect fluctuations in the representative household's discount factor.[12] As you can see, the NK model in that case results in a conventional Phillips curve that reflects a positive short-run output-inflation tradeoff.

12. The log-linearized version of the model is described in appendix A.

Figure 3. Slope of Phillips Curve Depends on Relative Demand and Supply Shocks

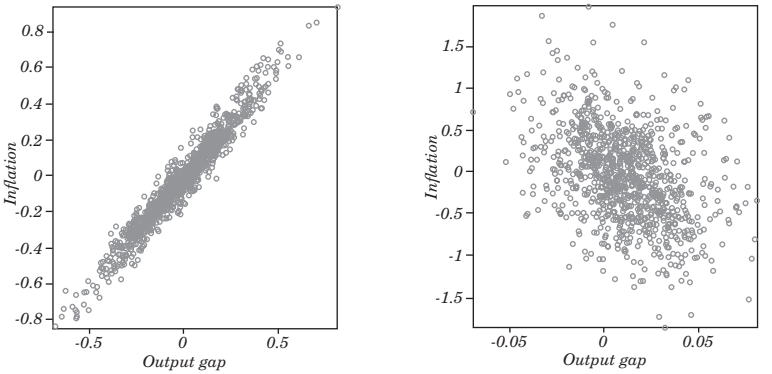
i. Demand-shock driven *ii. Demand + supply-shock driven*



Source: Author's calculations.

Figure 4. Phillips Curve in NK-model with Uncorrelated and Correlated Shock

i. Correlation demand and supply shocks: 0 *ii. Correlation demand and supply shocks:* 0.5



Source: Author's calculations.
Note: Plotted are comovement of inflation and output (percent deviations from steady state) in demand-shock-driven fluctuations under different assumptions about the correlation between demand and supply shocks.

The panel on the right in figure 3 shows the NK Phillips curve from the same model, but now for the case in which the demand (discount-factor) shocks are positively correlated with the supply shocks in the model. These supply shocks affect the marginal cost of production and shift firms' price-setting decisions. The panel plots the relationship between the percent deviation of output and inflation from their steady-state values when this correlation is 0.5. Even at this low correlation, the sign of the equilibrium reduced-form regression coefficient of inflation on output in the NK model changes from positive, i.e., the sacrifice ratio plotted in the left panel, to negative.

Thus, the importance of the correlation between demand and supply shocks for the empirical identification of the Phillips curve is not a moot point. It is relevant in the class of models most commonly used for monetary policy analysis by central banks.

Note that this observation that supply shocks might be important for shaping the recent relationship between output and inflation does not necessarily render monetary policy ineffective. Instead, it should make us think beyond (recent) monetary policy measures only affecting aggregate demand, as in the textbook AD-AS model as well as the conventional NK model.

In fact, there is a large number of research papers that, though not explicitly put in this context, already do so. For example, Ravenna and Walsh (2006) explicitly focus on the cost channel of monetary policy, where the interest rate that the central bank sets directly affects the marginal cost of production through the cost of financing working capital needed in production. Daly and Hobijn (2014) discuss how the equilibrium impact of downward nominal wage rigidities can be interpreted as a supply shock in that they affect the relationship between marginal cost and resource slack and thus firms' price-setting decisions and, in the simple AD-AS framework, the SRAS curve. The result is a flattening of the (wage) Phillips curve in their model. Gilchrist and others (2017) show how firms' liquidity levels affected their price-setting decisions, and thus the SRAS curve, during the financial crisis. Finally, Carlstrom and others (2017) show how quantitative easing also can have an effect on the supply side of the economy and potentially offset a negative supply shock.

The distinction of demand and supply shocks itself is largely a product of the AD-AS model being the workhorse model for the analysis of stabilization policies, where demand shocks affect preferences and supply shocks affect technology. This is in line with Ramey (2016), who

defines "...shocks we seek to estimate as the empirical counterparts to the shocks we discuss in our theories, such as shocks to technology, monetary policy, and fiscal policy." However, Ramey (2016) also points out that shocks "...(1) should be exogenous with respect to the other current and lagged endogenous variables in the model; (2) they should be uncorrelated with other exogenous shocks; otherwise, we cannot identify the unique causal effects of one exogenous shock relative to another."

In this sense "correlated demand and supply shocks" is an oxymoron. The oxymoronic observation that we have "correlated demand and supply shocks" poses challenges at three different levels.

At a theoretical level, it means that the common source that drives both of these shocks needs to be modeled. Since this common source moves both the AD and SRAS curves, the specific distinction between these two curves in the AD-AS, as well as NK, framework might not necessarily be the most useful in this case. As I discussed above, however, there are already many papers that are up to this challenge and introduce mechanisms that result in joint shifts of the AD and SRAS curves.

At a policy level, it is important that we realize that such mechanisms might invalidate our narrative of monetary policy offsetting demand shocks and managing fluctuations in aggregate demand along a relatively fixed SRAS curve. This means that the Fed's dual mandate of "price stability and maximum employment" does not necessarily involve a positive output-inflation tradeoff inherent in the existence of a Phillips curve.

Moreover, it also means that it is important for policymakers to clearly communicate the mechanisms through which monetary policy measures are transmitted to the supply side of the economy. The reason I cited the four papers with such mechanisms above is that all four of them provide clear insights into how monetary policy decisions affect the supply side of the economy: through affecting the cost of working capital of firms, greasing the wheels of the labor market, alleviating financial constraints, and quantitative easing.

Finally, at a measurement level, it is important to improve our understanding of and to account for the supply-side factors that drive the inflation rate that the central bank targets, i.e. PCEPI inflation in the United States. In the rest of this paper, I address this third challenge.

2. Measuring the Supply-Side Origins of Inflation

One approach is to study these supply-side factors that drive inflation in the context of a model. A model is useful because it allows for counterfactual analyses and is very explicit about the general equilibrium effects at play. In the simple three-equation NK model that I used in the previous section, the supply-side factors that determine current inflation are: (i) Expected future inflation, (ii) the degree of nominal (price) rigidities, and (iii) all things that affect the marginal cost of production. Of course, most of these models imply paths of demand and supply shocks that are correlated and thus do not have a structural interpretation.

Another approach, which is the one I am taking here, is to use an accounting framework to measure these supply-side factors. The type of accounting exercise, using dual growth-accounting techniques, that I perform here explicitly takes the scope of the costs of PCE into account and traces these costs along the domestic value-added chain as well as the costs of imports to account for the production factors that contribute to the value added that makes up personal consumption expenditures.

For example, wages make up the bulk of the (marginal) cost of production in the economy. Thus, using the right measure of wages is important.[13] The problem is that the wage measures most often used by economists are not constructed to measure the cost of production of *consumption goods*, but instead to cover all value added in the economy. This is also true for other measures of factors that capture marginal costs. The growth-accounting exercise that I perform is meant to construct the factor costs relevant for the production of PCE.

Of course, I am not the first to use growth-accounting techniques to account for supply-side factors in the economy. Long-run trend forecasts, like that for potential output in table 1–2 in Congressional Budget Office (2018) and the table on page 24 in Federal Reserve Board of Governors (2012), are mostly derived by using growth-accounting methods.

What distinguishes my accounting exercise from those that focus on trend growth is the following. First, the scope of my analysis is

13. For example, to deal with this, Justiniano and others (2013) use measurement equations for compensation per hour and average hourly earnings in the empirical state-space model that they estimate based on their DSGE model.

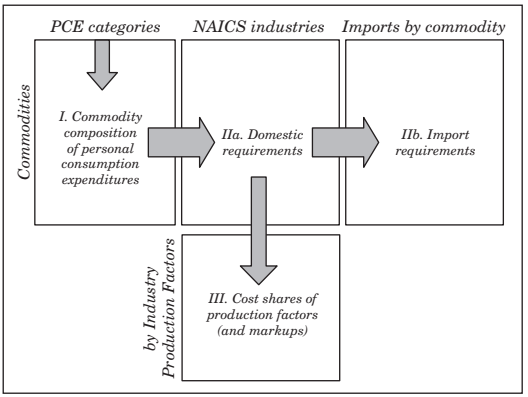
different. Because the Federal Reserve, just like most other central banks, focuses on consumer price inflation, and in particular the PCEPI, I focus on personal consumption expenditures rather than GDP. Second, I perform a *dual* growth-accounting exercise. Using this dual approach allows me to focus on the *price* of consumption goods rather than on the quantity. Finally, I consider the short-run rather than the long-run in that I decompose the annual percent change in the PCEPI.

The data requirements for the accounting exercise I perform here are steep. However, for the U.S. the data needed are part of the integrated Bureau of Labor Statistics/Bureau of Economic Analysis (BLS/BEA) industry-level production account and the BEA's annual input-output accounts. The combined annual data that I use cover 1998–2015.

2.1 The PCE Value Chain Has Been Relatively Stable

The first step in disentangling the supply-side factors that drive PCE inflation is to identify the sectors in the U.S. economy as well as the types of imports that account for the value added embodied in the final goods and services that households (and non-profits) buy. The PCE value chain uncovered in this step has been relatively stable over the 18 years covered in the data. This result, and how it is derived, is best understood in the context of figure 5.

Figure 5. Tracing Sources of Costs of PCE



Sources: BEA and OECD.

Panel I of the figure shows how the cost of consumer spending on different categories of goods and services is tracked to the commodities that make up these goods and services. For example, when one buys a bottle of milk at the supermarket, then part of this spending is classified as a retail sales commodity, i.e., the markup the supermarket charges, and part of it as a food manufacturing commodity, i.e., the supermarket's cost of the bottle of milk.[14]

Panels IIa and IIb show how we can trace the cost of the retail sales and food manufacturing commodities of this bottle of milk up the domestic supply chain. For example, part of the retail sales cost of the bottle of milk reflects the intermediate goods and services the supermarket buys, like its electricity bill which, in turn, reflects the cost of utilities. Part of the cost of the bottle of milk reflects the cost of intermediate goods and services bought by the dairy producer. Some of these intermediate goods and services, like the glass bottle and the milk, are themselves commodities produced in the United States. These domestically produced intermediate inputs can be traced further up the domestic value chain in terms of panel IIa of the figure. Other intermediate inputs of the dairy producer, like the plastic cap that seals the bottle, are imported from abroad. These imported intermediates cannot be traced further along the domestic value chain and are accounted for as separate supply-side factors.[15]

The part of the cost of the supermarket that sells the bottle of milk that is not due to the cost of intermediate goods and services is the value added that the supermarket contributes to the cost of the bottle of milk sold to consumers. Similarly, the part of the producer price of the bottle of milk that is not due to the intermediate goods and services the dairy producer buys is the value that dairy producer adds. At the end, the cost of the bottle of milk for consumers reflects both value added by domestic industries at different stages along the value chain as well as the cost of imported intermediates at different stages along the value chain.

14. Because the bottle of milk is simply resold by the supermarket and not transformed in the process of production it is not counted as an intermediate input of the supermarket.

15. The imports that are counted in the value-added chain are imports that are directly sold to final demand, consumers in the case of the analysis in this paper, and imports used as intermediate inputs. Imported capital goods that are used in production are accounted for as part of the factor cost of capital.

Tracing the cost of PCE up the domestic value chain to figure out the value added required in each industry as well as the imports required to produce the goods and services bought by consumers, as illustrated in figure 5, can be done by using input-output analysis. This yields what is known as total requirements for the production of the final goods and services that make up PCE. The math involved in this calculation is explained in subsection A.2 of appendix A.[16]

The results of tracing these total domestic and foreign requirements per dollar of PCE by subperiod, as well as the average over the whole period, are reported in table 1. As an example, the 15.8 in the row "Trade and transportation" for 1999 means that 15.8 cents per dollar of PCE spending in 1999 was produced as value added in the retail and wholesale trade and transportation industries.

Two things stand out from this table. The composition of the domestic requirements in part (a) of the table does not vary much over the subperiods reported. This suggests that the domestic part of the PCE value chain is relatively stable over time.[17] Most notable are the declines in the importance of manufacturing and of trade and transportation during the sample period, and the rise of the importance of education and health. Also note the low total requirement for government production for PCE.

The biggest change is the increased importance of imports for PCE spending from 1998 to the Great Recession in 2008, reported in the "Total imports" row in part (b) in table 1. Over that period, the import requirements for PCE spending increase from 7.9 cents on the dollar to 11.8 cents. Since the Great Recession, this has declined to 9.8 cents on the dollar in 2015. A lot of this decline has to do with energy imports.

Overall, though, the composition of the industries and the imports that account for the production of the value added that makes up the cost of PCE spending has been relatively stable over the 18 years in the sample. The relative stability of this composition does not necessarily mean the value chain itself has been stable. For example, the length of the value chain might have changed because of vertical specialization, as in Yi (2003).

16. See also ten Raa (2006) for an exposition of input-output analysis. The calculation of the total requirements for PCE here generalizes those applied in Hobijn (2008), Hale and Hobijn (2011), and Hale and others (2012).

17. Part of this might reflect that input-output data are collected relatively infrequently. This might result in these data understating the actual higher frequency fluctuations in these shares.

Table 1. Domestic and foreign Requirements per Dollar of Personal Consumption Expenditures (PCE) by Year

A. 1998–2007

	1998	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*
					Domestic requirements					
Agriculture, forestry, fishing, and hunting	1.3	1.1	1.1	1.1	1.0	1.2	1.3	1.1	1.1	1.1
Mining and utilities	2.7	2.7	2.7	2.6	2.5	2.6	2.8	2.8	3.0	3.1
Construction	0.5	0.5	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.9
Manufacturing	9.9	9.9	9.5	9.4	9.2	9.1	8.8	8.5	8.4	8.1
Trade and transportation	16.3	15.8	15.6	15.3	15.1	15.1	14.9	14.9	14.8	14.5
Information	4.1	4.2	3.9	3.9	4.1	4.0	4.2	4.0	3.8	4.1
Finance, insurance, and non-housing real estate	11.8	11.8	11.9	12.4	12.2	12.0	11.5	11.9	11.7	11.6
Housing	13.7	13.6	13.5	13.8	14.0	13.7	13.7	13.7	13.8	13.7
Professional and business services	8.6	8.7	8.9	8.8	8.9	8.8	8.8	8.8	8.8	9.1
Education and health	9.8	9.7	9.5	9.8	10.2	10.4	10.4	10.3	10.4	10.4
Arts, entertainment, and food services	5.1	5.3	5.3	5.1	5.3	5.2	5.3	5.2	5.2	5.2
Other services	5.0	4.9	4.8	4.5	4.5	4.4	4.3	4.2	4.2	4.1
Government	3.5	3.4	3.3	3.3	3.3	3.3	3.2	3.1	3.1	3.0
Other	0.5	0.6	0.6	0.6	0.6	0.4	0.4	0.4	0.4	0.4
Total value added	92.1	91.7	90.7	90.9	90.9	90.6	89.9	89.4	89.0	88.9
					Import requirements					
Materials	6.3	6.4	6.8	6.6	6.7	6.8	7.1	7.2	7.2	7.2
Energy	0.7	0.9	1.5	1.3	1.1	1.4	1.7	2.3	2.4	2.5
Services	0.5	0.5	0.5	0.6	0.7	0.7	0.7	0.7	0.9	1.0
Other	0.5	0.6	0.6	0.6	0.6	0.4	0.4	0.4	0.4	0.4
Total imports	7.9	8.5	9.4	9.1	9.0	9.3	10.0	10.5	10.9	11.0

Table 1. (continued)

B. 2008–2015 and 1998-2015 Average

	2008	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*Average*
					Domestic requirements				
Agriculture, forestry, fishing, and hunting	1.1	1.1	1.2	1.3	1.3	1.4	1.3	1.1	1.2
Mining and utilities	3.4	3.2	3.3	3.4	3.2	3.4	3.3	2.8	3.0
Construction	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8
Manufacturing	7.8	8.4	8.1	8.0	7.9	7.9	7.8	7.9	8.6
Trade and transportation	14.1	14.3	14.1	13.9	14.0	14.2	14.0	14.3	14.7
Information	4.1	4.0	4.1	3.9	3.8	4.0	3.8	4.0	4.0
Finance, insurance, and non-housing real estate	10.2	10.7	10.9	10.8	11.4	11.2	11.5	12.0	11.5
Housing	14.1	14.8	14.4	14.2	14.0	13.9	14.0	14.1	13.9
Professional and business services	9.5	9.0	9.0	9.1	9.2	9.2	9.3	9.5	9.0
Education and health	10.9	11.7	11.6	11.5	11.5	11.4	11.3	11.4	10.7
Arts, entertainment, and food services	5.1	5.1	5.1	5.0	5.2	5.3	5.4	5.5	5.2
Other services	4.0	4.0	3.9	3.8	3.8	3.8	3.9	3.9	4.2
Government	3.0	3.2	3.2	3.1	3.1	3.1	3.1	3.2	3.2
Other	0.4	0.4	0.3	0.3	0.2	0.3	0.3	0.4	0.4
Total value added	88.2	90.4	89.7	88.8	89.2	89.6	89.6	90.5	90.0
					Import requirements				
Materials	7.1	6.1	6.6	7.2	7.1	7.1	7.3	7.2	6.9
Energy	3.2	1.8	2.3	2.7	2.4	2.1	1.9	1.1	1.8
Services	1.1	1.2	1.1	1.1	1.1	1.1	1.1	1.0	0.9
Other	0.4	0.4	0.3	0.3	0.2	0.3	0.3	0.4	0.4
Total imports	11.8	9.5	10.4	11.3	10.9	10.6	10.6	9.8	10.0

Source: Author's calculations.

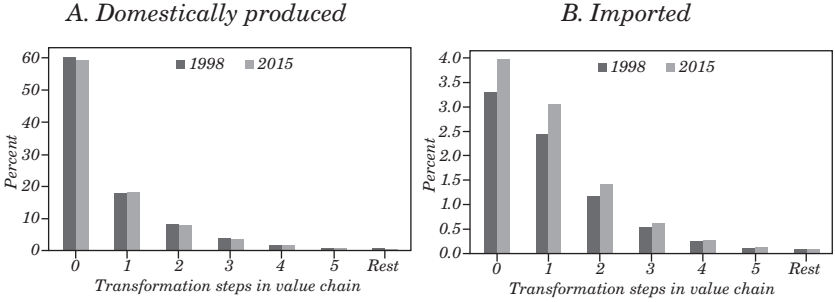
Note: Reported are cents of domestically produced and imported value added required for production of a dollar of PCE. Each column contains the average over period covered in column. Totals do not add up to 100 due to rounding.

There is little evidence for that in the data, though. The length of the domestic value chain has not changed much between 1998 and 2015. The main change has been where imports flow into the value chain. This can be seen from figure 6.

Panel (a) shows the cents of domestic requirements in a dollar of PCE by how many stages of transformation they go through before they are sold to final demand for both 1998 and 2015. This distribution can be used to gauge the length of the domestic supply chain. As can be seen from the figure, little has changed over the 18 years in the sample. What has changed is displayed in the right panel, i.e. panel (b). It shows how the import requirements, in cents on the dollar of PCE, are distributed along the number of transformation steps they take before they reach consumers. As can be seen from the figure, imports in 2015 flowed into the U.S. closer to final demand than in 1998. That is, imports in the U.S. take fewer steps along the supply chain now than 20 years ago.

The reason that it is important to look at the length of the supply chain is that several studies emphasize how the distortions due to nominal rigidities can be amplified along the supply chain in the economy.[18] The evidence here suggests that such amplification has not increased over the past two decades due to a lengthening of the value chain. This is because, just like the composition of total requirements in PCE, the length of the PCE value chain has been relatively constant over time.

Figure 6. Length of Value Chain for Requirements of a Dollar of PCE (1998 and 2015)



Sources: BLS, BEA, and author's calculations.
Note: Each bar reflects the number of steps a cent of value added takes downstream along the value chain before it is sold to final demand in terms of PCE.

18. See Huang and Liu (2001), Nakamura and Steinsson (2010), Pasten and others (2017).

2.2 Factor Requirements Reflect Decline of Labor Share

The next step in disentangling the supply-side factors that drive PCEPI inflation is to split up the industry value-added requirements into parts, due to different types of labor and capital used as factors of production. In terms of figure 5, this is reflected by the arrow from panel IIa to panel III. The results of this calculation are the total factor requirements that measure the cents on the dollar of PCE spending that can be traced to payments to different types of labor and capital.

These factor requirements are reported in table 2. Labor is split up into workers with and without a college education. The types of capital that are distinguished in the data are three: R&D, intangibles, information and communication technology (ICT) and a residual category. This would probably not be the classification of capital goods that a macroeconomist interested in inflation would choose, but it is the result of these data having been constructed for the analysis of long-run productivity trends.

On the labor side, the factor requirement of college-educated labor has steadily increased over the 18 years in the sample, from 22.8 cents on the dollar in 1998 to 25.9 in 2015. This increase is more than offset, however, by the decline in the factor requirement of non-college-educated labor that fell from 29.3 in 1998 to 22 in 2015. The net result is decline in the factor requirement of labor in the production of PCE goods and services, i.e., the *Labor-Total* row in the tables, from 52.1 in 1998 to 47.9 in 2015.

To compare this with more oft-cited measures of the labor share, one needs to consider this as a fraction of the domestic value-added requirement reported in the bottom row of the tables. This implies that the labor share of the domestically produced value added sold to consumers has declined from 56.5 to 52.9 percent. This means two things: First of all, the labor share in the domestic production of PCE goods and services is lower than in the nonfarm business sector. Second, the labor share in the domestic production of PCE goods and services has declined less than that in the nonfarm business sector.[19]

19. See Elsby and others (2013) for discussion of the time path of the latter labor share.

Table 2. Domestic Requirements per Dollar of Personal Consumption Expenditures (PCE) by Production Factor and Year

A. 1998–2007

	1998	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*
					Labor					
College	22.8	22.4	23.1	23.7	23.9	23.6	23.8	23.6	23.9	23.7
No college	29.3	28.9	27.9	27.8	26.7	26.5	25.6	25.0	24.5	24.4
Total labor	52.1	51.3	51.0	51.5	50.7	50.1	49.4	48.6	48.4	48.1
					Capital					
R&D	1.6	1.6	1.5	1.5	1.7	1.7	1.7	1.5	1.6	1.5
IT	2.7	2.8	2.8	2.8	2.7	2.6	2.4	2.3	2.2	2.1
Software	1.6	1.7	2.0	2.0	2.3	2.5	2.5	2.5	2.5	2.6
Other	33.6	33.7	33.0	32.5	32.9	33.1	33.2	33.8	33.8	33.8
Total capital	39.5	39.8	39.3	38.9	39.6	39.8	39.9	40.2	40.0	40.1
Total value added	92.1	91.7	90.7	90.9	90.9	90.6	89.9	89.4	89.0	88.9

Table 2. (continued)

B. 2008–2015 and 1998-2015 Average

	2008	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*Average*
	Labor								
College	23.6	24.3	23.9	24.2	24.9	24.9	24.8	25.9	24.0
No college	23.6	23.7	22.9	22.3	22.3	22.2	22.1	22.0	24.9
Total labor	47.2	48.0	46.8	46.5	47.2	47.0	46.9	47.9	48.8
					Capital				
R&D	1.5	1.7	1.7	1.7	1.6	1.7	1.8	1.9	1.6
IT	2.2	2.0	1.9	1.7	1.7	1.7	1.6	1.6	2.2
Software	2.5	2.6	2.6	2.5	2.5	2.5	2.6	2.8	2.4
Other	34.2	35.5	36.0	35.7	35.5	36.0	36.0	35.7	34.3
Total capital	40.3	41.8	42.1	41.6	41.3	41.9	42.0	41.9	40.6
Total value added	88.2	90.4	89.7	88.8	89.2	89.6	89.6	90.5	90.0

Source: Author's calculations.
Note: Reported are cents of domestically produced and imported value added required for production of a dollar of PCE. Each column contains the average over period covered in column. Totals do not add up to 100 due to rounding.

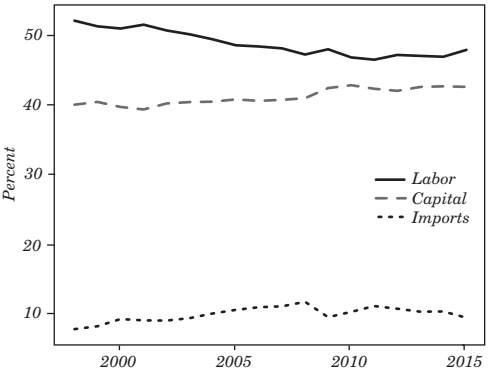
There is little evidence that the labor share of low-skilled workers in the domestic production of PCE goods and services has declined because of capital-labor substitution between low-skilled workers and ICT capital. If this was the case, then the decline in the factor requirement of non-college-educated workers should be mostly offset by an increase in the factor requirements of ICT capital and software. However, we have only seen a small increase in the factor requirements of these two types of capital.

Instead, two other mechanisms seem to be putting downward pressure on the PCE factor requirement of labor. They can be best seen when looking at figure 7. The figure plots the time series of factor requirements per dollar of PCE for labor and capital as well as the import requirements. As can be seen in the figure by comparing the line for "Labor" with the other two, the decline in the factor requirement of labor over the 18 years of the sample can be split into two episodes. In the first, from 1998 to 2008, when the labor requirement declined by 4 percentage points, it was offset by an increase in the import requirement. This is consistent with the cross-industry evidence from Elsby and others (2013) that declines in labor shares occurred in industries with more import competition, i.e., that there was import substitution of unskilled labor. During the second episode, from 2008 to 2015, the factor requirement of labor did not decline much, but that of unskilled labor did, and it was offset by an increase in that of skilled labor. The decline in the factor requirement of unskilled labor coincided with an increase in the factor requirement of other non-ICT and non-R&D capital. There are several potential explanations that are consistent with such a shift in factor requirements. Capital/non-skilled-labor substitution in response to low interest rates would be one of them.[20]

What is most striking from table 2 as well as figure 7 is that there are no obvious cyclical fluctuations in the factor requirements and that what is most important is the longer-run trends. An important caveat is the question whether the pattern in the eight years post-2008 is partly reflective of the prolonged low-interest rate regime the economy was in or a continuation of longer-run shifts in factor usage in the production of consumer goods and services.

20. Rognlie (2015) points out the importance of the increase in the factor share of housing and structures for the trend in the U.S. labor share in longer-run data.

Figure 7. Factor Requirements of a Dollar of PCE



Sources: BLS, BEA, and author's calculations.
Note: Shares of value added embodied in PCE traced to capital, labor, and imports.

2.3 Bulk of Inflation Fluctuations Related to Import Prices

The final step in disentangling the supply-side factors that drive PCEPI inflation is to calculate the importance of changes in the costs of production factors and import prices for PCEPI *inflation*. This translation can be done by using the realization that PCEPI inflation is approximately a weighted average of the percent changes in factor costs and import prices. The weights in this average correspond to the requirements reported in the previous two subsections. The formal mathematical derivation of this result is in subsection A.3 of appendix A.

I present the results obtained in this final step in three parts. First, I look at how much industries and imports contribute to PCE inflation. That is, I calculate the PCEPI inflation contributions based on the domestic and import requirements from panels IIa and IIb from figure 5. I then split up the contributions of domestically produced value added into those of different types of labor and capital. That is, I calculate the inflation contributions based on the factor requirements from panel III of figure 5. Finally, I take a more aggregate perspective and look at the PCEPI contributions of labor, capital, and imports over time.

How much each industry contributes to PCEPI inflation, as well as the inferred residual contribution of imports, is reported in table 3.[21] The top row of the table is the time series of annual PCEPI inflation that is decomposed.

21. The contribution of imports cannot be split up by type of imports because there are no import-price data by NAICS category before 2005.

Table 3. Contributions to Annual Personal Consumption Expenditures Price Index (PCEPI) Inflation from Value-Added Deflators by Industry and Imports

A. 1999–2007

	1999	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*
PCEPI	1.48	2.45	1.90	1.31	1.92	2.46	2.80	2.68	2.51
					Domestically produced value added				
Agriculture, forestry, fishing, and hunting	–0.16	–0.09	0.08	–0.09	0.12	0.19	–0.19	–0.05	0.28
Mining and utilities	–0.05	0.29	0.32	–0.17	0.42	0.23	0.43	0.22	0.11
Construction	0.03	0.04	0.04	0.03	0.03	0.05	0.08	0.07	0.05
Manufacturing	0.17	0.04	0.14	–0.04	–0.03	–0.04	0.35	0.13	0.02
Trade and transportation	0.12	0.31	0.05	0.02	–0.07	0.28	0.32	0.44	0.35
Information	–0.01	–0.04	–0.00	–0.02	–0.00	–0.04	–0.11	–0.07	–0.06
Finance, insurance, and non-housing real estate	–0.20	0.20	–0.01	0.24	0.35	0.32	0.26	0.19	0.20
Housing	0.42	0.40	0.51	0.54	0.30	0.28	0.29	0.37	0.28
Professional and business services	0.36	0.43	0.18	0.15	0.16	0.45	0.30	0.35	0.45
Education and health	0.31	0.33	0.47	0.35	0.33	0.32	0.32	0.27	0.42
Arts, entertainment, and food services	0.21	0.17	0.21	0.19	0.08	0.11	0.18	0.18	0.21
Other services	0.20	0.23	0.26	0.20	0.13	0.14	0.17	0.17	0.16
Government	0.09	0.11	0.18	0.11	0.23	0.30	0.31	0.21	0.01
Total domestically produced	1.50	2.40	2.43	1.51	2.04	2.59	2.71	2.48	2.48
					Imported value added				
Imports	–0.02	0.05	–0.53	–0.20	–0.12	–0.13	0.09	0.20	0.03

Table 3. (continued)

B. 2008–2015 and 1999-2015 Average

	2008	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*Average*
PCEPI	2.95	–0.09	1.70	2.50	1.89	1.34	1.49	0.25	1.86
					Domestic requirements				
Agriculture, forestry, fishing, and hunting	0.02	–0.27	0.15	0.33	0.03	0.03	–0.11	–0.22	0.00
Mining and utilities	0.41	–0.57	0.24	0.19	–0.19	0.11	0.09	–0.60	0.09
Construction	0.00	0.01	–0.02	0.01	0.03	0.03	0.05	0.03	0.03
Manufacturing	0.19	0.35	0.10	0.39	0.36	0.03	0.18	0.13	0.14
Trade and transportation	0.35	0.49	0.19	0.28	0.41	0.18	0.17	0.34	0.25
Information	–0.05	–0.00	–0.03	–0.02	0.00	0.03	–0.00	–0.07	–0.03
Finance, insurance, and non-housing real estate	0.07	–0.52	0.28	0.19	0.42	0.36	0.41	0.34	0.18
Housing	0.19	0.22	–0.09	0.12	0.29	0.28	0.30	0.44	0.30
Professional and business services	0.12	0.14	0.08	0.10	0.13	0.15	0.10	0.26	0.23
Education and health	0.23	0.41	0.26	0.17	0.21	0.15	0.15	0.21	0.29
Arts, entertainment, and food services	0.16	0.26	–0.00	–0.01	0.20	0.14	0.13	0.25	0.16
Other services	0.16	0.19	0.10	0.09	0.10	0.12	0.10	0.14	0.16
Government	–0.05	–0.03	0.10	0.06	0.10	0.12	0.13	–0.00	0.12
Total domestically produced	1.81	0.69	1.37	1.90	2.09	1.72	1.71	1.26	1.92
					Imported value added				
Imports	1.15	–0.78	0.33	0.60	–0.21	–0.38	–0.22	–1.01	–0.07

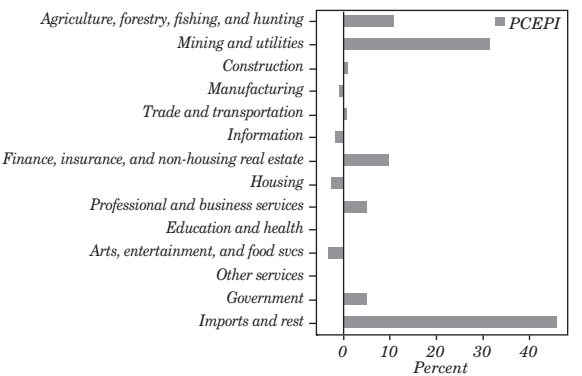
Sources: BLS, BEA, and author's calculations.
Note: The "Average" column contains the average over the 17 years in the sample.

Housing, education and health, and trade and transportation are, on average, the biggest contributors to headline inflation. This can be seen from the final column of table 3, labeled "Average". It lists the average percentage point contribution of each of the industries as well as imports to the 1.86 percent average annual rate of PCEPI inflation from 1999 to 2015. Together these three top contributing sectors account for 0.84 percentage points of the 1.86 percent average inflation.

However, these averages do not reflect the importance of these industries for inflation fluctuations. Three quarters of inflation *fluctuations* can be traced back to imports and to mining and utilities. This can be seen from figure 8, which decomposes the variance of annual PCEPI inflation over the 17 years in the sample into fluctuations in the contributions by industries and by imports. This result emphasizes the importance of commodity, especially oil, price fluctuations for headline PCEPI inflation.

The contributions of domestically produced value added to PCEPI inflation are divided into the parts due to different types of labor and to different types of capital in table 4. The "Average" column of the table shows that, in terms of levels, labor inputs account for two thirds of the average 1.86 percent of inflation over the 17 years for which I have data, IT capital costs reduce inflation by 0.2 percentage points, while measured TFP growth lowers inflation by 0.25 percentage points.

Figure 8. Variance Decomposition of Annual PCEPI Inflation by Industry and Imports



Sources: BLS, BEA, and author's calculations.
Note: Percent of variance of PCEPI due to industry and imports.
Reported is covariance between PCEPI inflation and industry and import contribution to PCEPI inflation as share of variance of PCEPI inflation.

Table 4. Contributions from Production Factors to Annual PECPI Inflation, 1999–2015

A. 1999–2007

	1999	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*
					Labor				
College	0.35	1.81	1.54	0.26	0.41	1.37	1.15	0.88	0.08
No college	1.22	0.95	1.22	0.60	1.07	0.70	0.80	0.72	0.96
Total labor	1.57	2.76	2.76	0.85	1.48	2.07	1.96	1.60	1.04
					Capital				
Art	0.11	–0.16	0.04	0.12	–0.03	0.06	–0.01	0.01	0.05
R&D	0.01	–0.04	0.01	0.16	0.04	0.07	0.00	0.10	–0.00
IT	–0.40	–0.43	–0.43	–0.36	–0.18	–0.22	–0.11	–0.20	–0.22
Software	–0.09	0.04	–0.12	0.18	0.03	0.04	–0.10	–0.02	0.10
Other	1.34	0.60	–0.06	1.01	1.22	1.67	1.98	0.78	0.92
Total capital	0.98	0.01	–0.56	1.12	1.07	1.62	1.76	0.68	0.84
					Measured productivity growth				
TFP	–1.05	–0.37	0.23	–0.46	–0.51	–1.10	–1.00	0.20	0.59
Total value added	1.50	2.40	2.43	1.51	2.04	2.59	2.71	2.48	2.48

Table 4. (continued)

B. 2008–2015 and 1999-2015 Average

	2008	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*Average*
					Labor				
College	0.35	1.81	1.54	0.26	0.41	1.37	1.15	0.88	0.08
No college	1.22	0.95	1.22	0.60	1.07	0.70	0.80	0.72	0.96
Total labor	1.57	2.76	2.76	0.85	1.48	2.07	1.96	1.60	1.04
					Capital				
Art	0.01	–0.03	0.07	–0.02	–0.00	–0.00	–0.06	0.02	0.01
R&D	–0.03	–0.01	0.05	0.02	0.00	0.08	0.05	0.05	0.03
IT	–0.13	–0.34	–0.14	–0.13	–0.03	–0.04	–0.06	–0.00	–0.20
Software	–0.13	0.00	0.02	–0.01	–0.02	–0.04	0.13	0.04	0.00
Other	0.45	0.11	2.27	1.28	1.02	1.25	1.17	0.26	1.02
Total capital	0.16	–0.27	2.28	1.14	0.98	1.25	1.22	0.36	0.86
					Measured productivity growth				
TFP	1.46	0.00	–1.74	0.17	–0.15	0.13	–0.68	–0.29	–0.27
Total value added	1.81	0.69	1.37	1.90	2.09	1.72	1.71	1.26	1.92

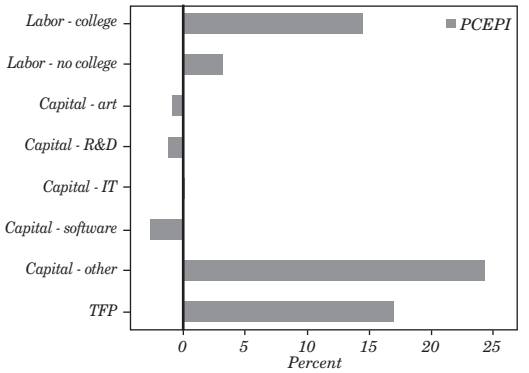
Sources: BLS, BEA, and author's calculations.
Note: The "Average" column contains the average over the 17 years in the sample.

Just like for the industry-level analysis in table 3, the factor-level analysis in table 4 is misleading about the relative importance in terms of inflation *fluctuations*. The relative importance of changes in the cost of domestic production factors for inflation is shown in figure 9. Three things stand out from this figure. The first is the relative importance of the fluctuations in factor costs of other types of capital for inflation.

The second is the importance of fluctuations in TFP growth. In its purest form, these are the supply shocks I discussed above. In practice, of course, the *measured* contributions of capital and TFP to PCE inflation are both potentially affected by the cyclicality of markups, which the type of growth-accounting method I use here does not take into account.

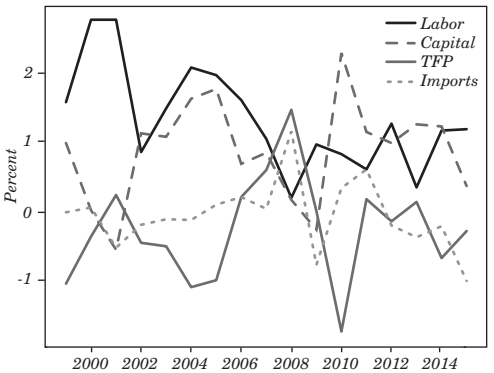
Finally, most surprisingly, fluctuations in the compensation of college-educated labor are four times more important for inflation fluctuations than those of non-college-educated labor. This possibly reflects two things. First of all, that wages of non-college-educated workers are stickier, partly due to minimum wage restrictions and to them being disproportionately determined by union bargaining. Secondly, as Elsby and others (2013) show, a large part of aggregate fluctuations in compensation per hour is accounted for by sectors that pay bonuses. Thus, to some extent, the relative importance of fluctuations in the compensation of college-educated workers for inflation might be due to non-wage and salary aspects of compensation.

Figure 9. Variance Decomposition of Annual PCEPI Inflation for Production Factors



Source: BLS, BEA, and author's calculations.
Note: Percent of variance of PCEPI due to production factors.
Reported is covariance between PCEPI inflation and factor contribution to PCEPI inflation as share of variance of PCEPI inflation. Total does not add up to 100 because figure excludes contribution of imports.

Figure 10. Factor Contributions to Annual PCEPI Inflation



Sources: BLS, BEA, and author's calculations.
Note: Percentage point contribution of production factors, measured productivity growth (TFP), and import-price inflation to annual (yr/yr) PCEPI inflation.

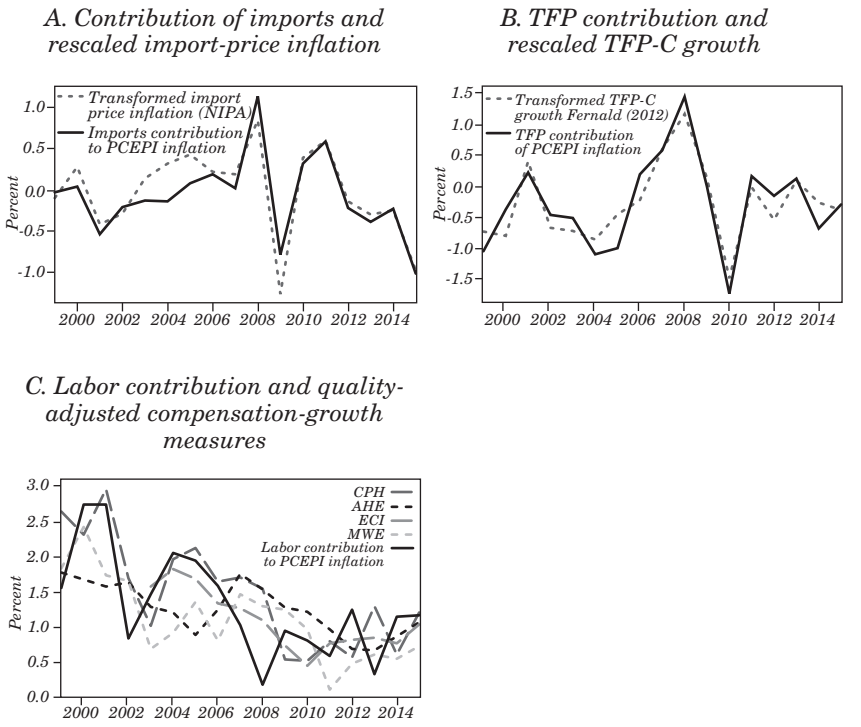
Of course, most macroeconomists neither distinguish between college- and non-college-educated labor nor between different types of capital. For that reason, figure 10 plots the time series for the contributions of labor, capital, measured TFP, and imports to PCEPI inflation. The shares of inflation fluctuations that they account for are: 17.6, 19.7, 17.0, and 45.7 percent, respectively. That is, even though labor compensation accounts for the bulk of the cost if PCE spending, it only accounts for less than a fifth of inflation fluctuations. Fluctuations in the measured cost of capital and measured TFP growth tend to largely offset each other, possibly because of unaccounted movements in markups. This results in the contributions of these factors not comoving that much with headline inflation. Finally, though imports only make up a tenth of the cost of PCE spending, they play an outsized role in fluctuations in PCEPI inflation.

3. Real-Time Rule-of-Thumb Approximation

The measurement of the supply-side origins of PCEPI inflation that I presented in the previous section relies on data on U.S. input-output relationships and productivity accounts by industry, which are released with a substantial delay. In fact, the data that I use was released in November 2017 and only covers years through 2015.

Thus, in practice, the type of supply-side accounting for inflation that I do here might not be practical for the real-time analysis of inflation. It turns out, however, that several of the main results of subsection 2.3 can be approximated by using simple rules of thumb that are implementable in real time. These real-time rule-of-thumb approximations are shown in figure 11.

Figure11. Real-Time Rule-of-Thumb Approximation of Supply-Side Origins of Inflation



Sources: BLS, BEA, Fernald (2012), and author's calculations.
Note: Rescaled import-price inflation is $0.1\pi_t^M - 0.15$, where π_t^M is annual inflation in the implicit price deflator of imports of goods and services (NIPA, table 4.2.4, line 26). Rescaled TFP –C growth is $-0.5\Delta tfp_{c,t} - 0.25$, where $\Delta tfp_{c,t}$ is TFP-C from Fernald (2012). Quality-adjusted compensation-growth is $0.5(\Delta w_t - \Delta LQ_t)$, where Δw_t is annual growth rate of the respective compensation measure and ΔLQ_t is the growth rate of labor quality, based on Aaronson and Sullivan (2003), from Fernald (2012).

The top panel of the figure, i.e., panel (a), shows how the contribution of imports to annual PCE inflation can be closely approximated by $0.1\pi_t^M - 0.15$, where π_t^M is annual inflation in the implicit price deflator of imports of goods and services (NIPA, table 4.2.4, line 26).[22] The coefficient of 0.1 is in line with total import requirements reported in table 1. The deduction of 0.15 is a mean correction due to the rescaling of the import-price inflation rate.

As can be seen from the figure, this rule-of-thumb approximation does a very good job tracking the contribution of import-price inflation to PCE inflation. It is simple to calculate when one wants to gauge the importance of import-price inflation for PCE inflation when one does not have the input-output and productivity data that I relied on here.

The middle panel, i.e., panel (b), shows that the TFP contribution to PCE inflation lines up closely with total factor productivity growth of consumption goods from Fernald (2012)'s quarterly TFP growth data, published by the Federal Reserve Bank of San Francisco. In particular the TFP contribution to PCEPI inflation is approximately equal to $-0.5\Delta tfp_{c,t} - 0.25$, where $\Delta tfp_{c,t}$ is annual TFP-C growth from Fernald (2012). Thus, the effect of measured productivity growth on the inflation rate that the Fed targets can, in principle, be gleaned from data published with less of a delay than the data I use and at a quarterly basis. This is with the caveat that the quarterly TFP data, based on Fernald (2012), are subject to revisions. But so is PCEPI inflation, of course.

The bottom panel, i.e., panel (c), compares the labor contribution to PCEPI inflation to four measures of quality-adjusted compensation growth for the U.S. In the BLS/BEA data that I use, labor costs are calculated based on industry compensation per quality-adjusted hour measures. The quality adjustment is done by using the method explained in Jorgenson and others (2017) and is based on CPS-ASEC (Current Population Survey – Annual Social and Economic Supplement) data on self-reported sector of employment and earnings of individuals.

I compare the labor-cost contribution to PCEPI inflation with four commonly used aggregate compensation-growth measures, ΔLQ_t, for the U.S., namely: average hourly earnings (AHE), compensation per hour (CPH), employment cost index (ECI), and median usual weekly

22. Note, however, that figure 11 is not constructed with real-time data but instead with the data available in September 2018, when the results were calculated. So the rule-of-thumb approximation that is depicted is not real-time.

earnings (MWE). I adjust these compensation-growth measures for aggregate changes in labor quality by using the measure, ΔLQ_t, based on Aaronson and Sullivan (2003), from Fernald (2012).

Panel (c) shows the labor contribution to PCEPI inflation as well as 0.5 times the growth rate in quality-adjusted labor compensation based on each of these four measures. As can be seen from the figure, the labor contribution to PCEPI inflation is best approximated by rescaled quality-adjusted CPH and ECI growth. However, these two, as well as the other compensation-growth measures, overstate the contribution of labor costs to inflation in both the 2001 and 2008 recessions. That is, the contribution of labor-cost growth to headline PCE inflation is more procyclical than commonly used in macroeconomic time series of wage growth. This might partly reflect that the cost of PCE spending does not depend much on government production and thus on the wages of government workers, which tend to be less sensitive to market forces that drive business-cycle fluctuations.

A rule of thumb for the contribution of the cost of capital to PCEPI inflation is hard to find. This is because, being a user cost, this cost depends on a lot of factors: the composition of the capital stock used in producing PCE goods and services, depreciation rates, the internal rate of return of businesses, and the price of investment goods. In addition, due to the way the productivity statistics are calculated, capital is effectively the residual claimant in the factor attribution of revenue. As a consequence, changes in the measured cost of capital are also affected by movements in markups.

Still, relatively simple rule-of-thumb calculations can be used to approximate the factor contributions to PCEPI inflation for three out of the four supply-side factors I consider. These approximations can be useful when discussing the importance of these factors for inflation in real time.

4. Beyond Neoclassical Assumptions and Beyond the U.S.

I hope the dual growth-accounting exercise in the previous two sections has convinced you that it is worthwhile for central banks to explicitly account for the supply-side factors that are at the root of the inflation rates that they target. As I discussed above, the methodology that I used is not new, I just applied it with a different scope, focused on prices rather than quantities, and used it to analyze short-run fluctuations.

Because of this, my analysis in this paper is subject to the same limitations as other studies that use growth-accounting methods. Most notably, it is based on neoclassical assumptions that ignore the possible existence of markups. It is, of course, the variation in such markups due to nominal rigidities that gives rise to the monetary transmission mechanism in most theoretical NK models. Thus, to further the use of supply-side analyses of inflation, it is important to extend growth-accounting methods to also account for markups.[23] To give an example of why accounting explicitly for markups is important, in figure 8 I found that mining and utilities accounts for about a third of inflation fluctuations in the U.S. These contributions largely reflect changes in markups in the industry due to fluctuations in oil prices.

My analysis here focused solely on the U.S. I used the integrated industry-level production accounts (ILPA) for the U.S. This data has been published since 2014. Unfortunately, doing similar analyses for other countries is hard because of the lack of recent integrated growth-accounting and input-output data. The initial vintage (2014) of the World Input-Output Database (WIOD)[24], included socio-economic accounts that allowed for the type of dual growth accounting I did here. Unfortunately, the most recent vintage (2016) does not include the data on capital needed to do so. Similarly, the current version of the OECD statistical analysis (STAN)[25], that contains data on Chile, does not include the necessary input-output data to do the analysis I did here.

This lack of data, in large part, reflects a lack of funding for statistical agencies and cross-country data collection efforts. I hope the analysis in this paper shows that such funding is important in order to collect and construct the data necessary to assess how national and global value-added chains, factor costs, and, hopefully soon, markups drive the headline numbers that policymakers focus on.

It is imperative that central banks emphasize the importance of this type of data and, if necessary, contribute to the collection and construction of data that better help us understand the changing mix and dynamics of supply-side factors that contribute to fluctuations in output and inflation.

23. Hall (1988) is an older paper that addressed growth accounting with markups for aggregate data. A similar method to apply in the context of the input-output analysis used here has not yet been developed.

24. Stehrer and others, 2014.

25. OECD, 2017.

5. Conclusion

The disappearance of an empirical Phillips curve relationship in the data is indicative of recent economic fluctuations being affected by (positively) correlated demand and supply shocks. The correlation between these shocks poses a challenge on three different fronts.

Theoretically, we need models to better understand the source of these common fluctuations in demand and supply forces. There are several existing studies that provide such explanations but that do not explicitly place their results in this context. A reinterpretation of theories in this framework is useful.

In terms of policy, this disappearance of the Phillips curve does *not* mean that monetary policy has become ineffective. It is a reminder that it is important to understand and communicate the transmission of monetary policy measures to the production, rather than spending, side of the economy. It does indicate, though, that the Fed's dual mandate of "price stability and maximum employment" does not always involve a tradeoff.

The final challenge is to better measure the supply-side factors that drive inflation. In this paper, I use dual growth-accounting methods, normally applied for the analysis of long-run growth and productivity trends, to account for the supply-side factors that drive annual PCEPI inflation from 1999 to 2015.

I show that the value chain of PCE goods and services that determines the composition of the costs that drive PCEPI has been relatively constant over time. The two main trends are the increased importance of imports from 1998 to 2008 and the steady decline of the factor requirement of (unskilled) labor over time.

The relative shares of the supply-side factors in the cost of PCE goods and services, however, are not indicative of their relative importance for inflation *fluctuations*. In terms of changes in inflation over time, import-price inflation turns out to be the most important factor. Even though imports only account for a tenth of the cost of PCE, fluctuations in import prices drive 45 percent of fluctuations in inflation. The contributions of capital and measured TFP growth largely offset each other. Finally, even though labor accounts for about half of the cost of PCE goods and services, changes in compensation only drive a fifth of inflation fluctuations.

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APPENDIX A

Mathematical Details

A.1 Simple New Keynesian (NK) Model

The three-equation NK model that is simulated in section 1 boils down to the following log-linearized equations:

$$\hat{y}_t = \mathbb{E}_t \hat{y}_{t+1} - \frac{1}{\sigma}\left(\hat{R}_t - \mathbb{E}_t \hat{\pi}_{t+1}\right) + (1-\rho_D)\hat{z}_{D,t}, \tag{1}$$

$$\hat{\pi}_t = \beta \mathbb{E}_t \hat{\pi}_{t+1} + \kappa\left(\varphi + \sigma\right)\hat{y}_t + \kappa(1+\varphi)\hat{z}_{S,t}, \tag{2}$$

$$\hat{R}_t = \left(\phi_\pi \hat{\pi}_t + \phi_y \hat{y}_t\right). \tag{3}$$

The table below lists these parameters and the definition of the equilibrium variables:

Variable	*Description*	*Value*
	Equilibrium variables	
$\hat{y}_t$	Output gap	-
$\hat{\pi}_t$	Inflation	-
$\hat{R}_t$	% deviation of gross from steady state	
	Shocks	
$a_{D,t}$	Demand shock	-
$z_{S,t}$	Supply shock	
	Parameters	
θ	Price stickiness	0.75
σ	Intertemporal elasticity of substitution	2
φ	Frisch elasticity of labor supply	3
β	Discount factor	0.99
φ_π	Inflation coefficient in Taylor rule	1.5
φ_y	Output-gap coefficient in Taylor rule	0.125
ρ_D	Persistence parameter of demand shocks	0.9
ρ_s	Persistence parameter of supply shocks	0

Source: Author's calculations.
Note: . $\hat{}$ denotes percentage deviation from steady state. Here $\kappa=(1-\theta)(1-\theta\beta)/\theta$.
The parameters of this model are calibrated for a quarterly frequency.

A.2 Derivations for Subsections 2.1 and 2.2

Though supply chains are often analyzed in terms of input-output analysis, I find it easier to think of them in terms of discrete-state Markov Chains. This is the interpretation that I use here. We will follow a dollar of final demand by consumers, i.e., a dollar of PCE, up the supply chain to where it either was imported or where it was created in terms of domestic value added. We denote the number of steps it has taken up the supply chain by s.

Throughout its journey up the supply chain this dollar can end up in three states. Either it can still be going up the supply chain in the form of gross output, or it has been traced to come from imports, or it has been traced to domestic value added in a particular industry. The latter two are absorbing states in that they are the origin of the value added (either foreign or domestic) that the dollar of PCE embodies.

In the following, the $(n_c \times 1)$-vector $\boldsymbol{c}_0$ represents the distribution of the dollar of PCE across the consumption categories. Because it reflects a distribution, $\iota'\boldsymbol{c}_0 = 1$, where ι is the summation operator, i.e., a vector of ones.

The $(n_j \times 1)$-vector $\boldsymbol{y}_s$ traces the fraction of the dollar of PCE that is still going up the supply chain after s steps. That is, the k^{th} element of $\boldsymbol{y}_s$ is the fraction of the dollar of PCE that was part of output of commodity k and then took s steps of transformation along the supply chain before it was sold to consumers.

The $(n_j \times 1)$-vector $\boldsymbol{m}_s$ is the fraction of the dollar of PCE, by commodity, that is imported into the U.S. and then takes s steps before it gets sold to consumers. The $(n_j \times 1)$-vector $\boldsymbol{v}_s$ is the fraction of the dollar of PCE that is produced, by industry, and goes through s transformation steps before ending up being sold to consumers. Each element in this vector corresponds to an industry.

We combine the last three vectors into a large $((2n_j + n_j \times 1)$-)-vector over which we define the Markov chain.

$$\boldsymbol{x}_s = \left[\boldsymbol{y}_s' \ \boldsymbol{m}_s' \ \boldsymbol{v}_s' \right]'. \tag{4}$$

The starting value $\boldsymbol{x}_0$ is determined by whether the consumption goods and services are made in the U.S.A. or imported from abroad. The $(n_j \times n_c)$-matrix $\boldsymbol{C}_y$ has the $(k,l)^{th}$ element that is the fraction of the consumption of category l that is supplied domestically. It is the part of the l^{th} element of $\boldsymbol{c}_0$ that is part of the k^{th} element of $\boldsymbol{y}_0$. Similarly,

the $(n_j \times n_c)$-matrix $\boldsymbol{C}_m$ has the $(k,l)^{th}$ element that is the fraction of the consumption of category l that is imported and directly sold to final demand.

Given this definition, the starting value $\boldsymbol{x}_0$ can be written as

$$\boldsymbol{x}_0 = \begin{bmatrix} \mathbf{C}_y \\ \mathbf{C}_m \\ 0_{(n_i \times n_j)} \end{bmatrix} \boldsymbol{c}_0 . \tag{5}$$

Note that $\iota' \boldsymbol{C} = \iota'$, i.e., the column sums of $\boldsymbol{C}$ are one. The next step is to follow the dollar of PCE that is part of $\boldsymbol{y}_0$ up the U.S. domestic supply chain.

For this purpose, I define three matrices. The first, $\boldsymbol{A}_y$, is an $(n_j \times n_j)$-matrix for which the $(k,l)^{th}$ element is the domestically produced intermediate input revenue share of commodity k in gross output of commodity l. These shares are reported as part of the domestic direct requirements matrix in the BEA's annual input-output tables. The second, $\boldsymbol{A}_m$, is an $(n_j \times n_j)$-matrix for which the $(k,l)^{th}$ element is the imported intermediate input revenue share of commodity k in gross output of commodity l. These shares are derived by subtracting the domestic direct requirements matrix from the total direct requirements matrix. Finally, $\boldsymbol{A}_v$ is an $(n_j \times n_j)$-matrix for which the $(k,l)^{th}$ element is the value-added share of industry k in gross output of commodity l.[26] This matrix is derived by combining the direct requirements matrix with the make table.

$$\boldsymbol{x}_{s+1} = \begin{bmatrix} \mathbf{A}_y & 0 & 0 \\ \mathbf{A}_y & 0 & 0 \\ \mathbf{A}_v & 0 & 0 \end{bmatrix} \boldsymbol{x}_s = \mathbf{A}\boldsymbol{x}_s . \tag{6}$$

The matrix $\boldsymbol{A}$ is defined such that I drop the value of the dollar of PCE as soon as it ends in one of the absorbing states, i.e., when I have traced back the source of the value added. Moreover,

$$\boldsymbol{\iota}' \mathbf{A} = \begin{bmatrix} \boldsymbol{\iota}'_{\boldsymbol{n}_j} & 0'_{\boldsymbol{n}_j} & 0'_{\boldsymbol{n}_i} \end{bmatrix}.$$

26. More than one industry can have a non-zero share in each column of this matrix because some commodities are produced by more than one industry.

Defining the transition matrix this way means that $\boldsymbol{x}_s$ has the following two properties:

$$\lim_{s\to\infty} \boldsymbol{x}s = 0_{((2n_j+n_i)\times 1)} \text{ and } \sum_{s=0}^{\infty} \left[0'_{\boldsymbol{n}_j} \;\; \boldsymbol{\iota}'_{\boldsymbol{n}_j+\boldsymbol{n}_i} \right] \boldsymbol{x}s = 1. \tag{7}$$

These two properties imply that the whole dollar of value added will be distributed into either imported value added or domestic value added along the supply chain that we decompose. The latter property in (7) is useful, because it means that our decomposition of a dollar of PCE can be written as

$$1 = \boldsymbol{\iota}' \boldsymbol{c}_0 = \sum_{s=0}^{\infty} \iota'_{n_i} \boldsymbol{v}_s + \sum_{s=0}^{\infty} \iota'_{n_j} \boldsymbol{m}_s . \tag{8}$$

This allows us to trace where the value added that is sold to final demand in the form of nominal PCE originates, both domestically, by industry, and foreign, by imported commodity. For each industry, the value-added requirements in $\boldsymbol{v}_s$ can then be divided into the factor requirements of the different types of labor and capital based on data on factor shares by industry.

A.3 Derivations for Subsection 2.3

To understand the dual growth accounting that allows us to measure the supply-side factors that drive PCE inflation, we split the nominal parts of (8) into their price and quantity components. I denote the price of PCE, i.e., the PCEPI, by P_c and the quantity by C. Thus, nominal PCE is equal to $P_c C$.

Throughout my derivations, I use a continuous-time notation, which I will approximate with a Törnqvist index in the empirical implementation. The goal is to account for the supply-side factors that drive the growth rate of the PCEPI, which, in continuous time, is the change in the log of P_c, i.e., $\pi_c = \dot{p_c}$. Here $\dot{}$ denotes the time derivative in continuous time and $\pi_c = \ln \dot{P_c}$. The growth of nominal PCE is the sum of inflation and the growth rate of the quantity, i.e., $\pi_c = \dot{c}$.

Nominal value added of industry i that ends up being sold to consumers after s steps along the supply chain is

$$V_s^C(i) = \boldsymbol{v}_s(i) P_C C, \tag{9}$$

where $\boldsymbol{v}_s(i)$ is the i^{th} element of $\boldsymbol{v}_s$. This makes up a fraction $F_s^V(i) = \dfrac{V_s^C(i)}{V(i)}$ of total value added of industry i.

Nominal value of imports of commodity j that end up being sold to consumers after s steps along the supply chain is

$$M_s^C(j) = \boldsymbol{m}_s(j) P_C C, \tag{10}$$

where $\boldsymbol{m}_s(j)$ is the j^{th} element of $\boldsymbol{m}_s$. This makes up a fraction $F_s^M(j) = \dfrac{M_s^C(j)}{M(j)}$ of imports of commodity j.

This allows us to write nominal PCE in terms of the origins of the value added it encompasses. That is, we obtain that

$$P_C C = \sum_{s=0}^{\infty} \sum_{i=1}^{n_i} F_s^V(i) V(i) + \sum_{s=0}^{\infty} \sum_{j=1}^{nj} F_s^M(j) M(j). \tag{11}$$

Taking the time derivative on both sides of this expression, we find that

$$\left(P^C C\right)\dot{p}^C + \left(P^C C\right)\dot{c} = \sum_{s=0}^{\infty} \sum_{i=1}^{n_i} (F_s^V(i) V(i)) \dot{f}_s^V(i) \tag{12}$$

$$+ \sum_{s=0}^{\infty} \sum_{j=1}^{nj} (F_s^M(j) M(j)) \dot{f}_s^M(j)$$

$$+ \sum_{s=0}^{\infty} \sum_{i=1}^{n_i} (F_s^V(i) V(i)) \dot{v}(i) + \sum_{s=0}^{\infty} \sum_{j=1}^{nj} (F_s^M(j) M(j)) \dot{m}(j). \tag{13}$$

When we define the shares of each of the components in nominal PCE as

$$\phi_s^V(i) = \frac{F_s^V(i) V(i)}{P^C C} \text{ and } \phi_s^M(j) = \frac{F_s^M(j) M(j)}{P^C C} \tag{14}$$

and divide both sides of this equation by the value of nominal PCE, we obtain that the growth rate of nominal PCE is a share-weighted average of the growth rates of the value-added components that flow to final demand in the form of consumption. That is,

$$\dot{p}^C + \dot{c} = \sum_{s=0}^{\infty} \sum_{i=1}^{n_i} \phi_s^V(i) \dot{f}_s^V(i) + \sum_{s=0}^{\infty} \sum_{j=1}^{nj} \phi_s^M(j) \dot{f}_s^M(j) \tag{15}$$

$$= \sum_{s=0}^{\infty} \sum_{i=1}^{n_i} \phi_s^V(i) \dot{v}(i) + \sum_{s=0}^{\infty} \sum_{j=1}^{nj} \phi_s^M(j) \dot{m}(j). \tag{16}$$

The next step is to split nominal value-added growth of each industry in a price and quantity component, i.e.

$$\dot{v}(i) = \dot{p}^V(i) + \dot{q}^V(i) \tag{17}$$

and

$$\dot{m}(j) = \dot{p}^M(j) + \dot{q}^M(j). \tag{18}$$

Doing so yields that

$$\dot{p}^C + \dot{c} = \sum_{s=0}^{\infty}\sum_{i=1}^{n_i}\phi_s^V(i)\dot{p}^V(i) + \sum_{s=0}^{\infty}\sum_{j=1}^{n_j}\phi_s^M(j)\dot{p}^M(j) \tag{19}$$

$$+\sum_{s=0}^{\infty}\sum_{i=1}^{n_i}\phi_s^V(i)\dot{f}_s^V(i) + \sum_{s=0}^{\infty}\sum_{j=1}^{n_j}\phi_s^M(j)\dot{f}_s^M(j) \tag{20}$$

$$+\sum_{s=0}^{\infty}\sum_{i=1}^{n_i}\phi_s^V(i)\dot{q}^V(i) + \sum_{s=0}^{\infty}\sum_{j=1}^{n_j}\phi_s^M(j)\dot{q}^M(j). \tag{21}$$

In the above equation, the bottom two lines have to do with the growth rates of quantities; this means that PCEPI inflation, i.e., $\dot{p_c}$, is equal to the top line, namely

$$\pi^C = \dot{p}^C = \sum_{s=0}^{\infty}\sum_{i=1}^{n_i}\phi_s^V(i)\dot{p}^V(i) + \sum_{s=0}^{\infty}\sum_{j=1}^{n_j}\phi_s^M(j)\dot{p}^M(j). \tag{22}$$

That is, consumer price inflation is the weighted sum of value-added deflator inflation by industry and import-price inflation by commodity.

Implementing (18) empirically requires combining data on nominal imports with import prices, both by commodity.[27] However, because of a lack of the necessary detail in the data, I report the second term on the right-hand side of (22) as the residual that makes the above equation hold. This is why it is labeled "Imports and rest" in the tables. The fact that the implied $\dot{p}^M$ from this residual closely lines up with rescaled import-price inflation from the NIPA, as I show in the section on rules of thumb, confirms that this is a reasonable approximation.

Under neoclassical assumptions of constant returns to scale and perfect competition in both the product and factor-input markets, (17)

27. In practice, this turns out to be infeasible in U.S. data because of the lack of import prices by NAICS classified commodities before 2005.

can be rewritten further by using dual growth-accounting methods. In particular, these methods allow us to split inflation in the value-added deflator for industry up into the changes in factor costs for the industry and measured TFP growth:

$$\dot{p}^V(i) = \sum_l s_l^V(i)\dot{w}_l(i) - \sum_k s_k^V(i)\dot{uc}_k(i) - \dot{z}(i). \tag{23}$$

Here $s_l^V(i)$ is the factor share of labor of type l in value added and $\dot{w}(l)$ is quality-adjusted compensation growth for labor of type l in industry i. Similarly, $s_k^V(i)$ is the factor share of capital of type k in value added and $\dot{uc}_k(i)$ is the growth rate of the user cost of capital of type k industry i. The term $\dot{z}(i)$ is measured TFP growth in sector i. Combined with (17), this allows for decomposing π^c into parts due to labor, capital, and TFP in different industries and due to import prices.

The derivations here are in continuous time. Of course, in practice, the data are provided on an annual basis. Following Fleck and others (2014), I use a Törnqvist index to approximate these continuous-time equations in discrete time.