Discussion Paper Series A No.733

Hidden Stagflation

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July 2022

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July 4, 2022

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Abstract

We present evidence that the rise in inflation in Japan since 2014 is a result of a hidden stagflation: the relative prices of durable consumption and ICT investment goods stopped declining, reflecting technology stagnation and exerting an inflationary pressure on the economy and; the real side of the Japanese economy simultaneously started stagnating even further. We construct a multi-good monetary model to account for these facts together and quantify the impact of the technology stagnation on the aggregate inflation rate. We develop a new sign restriction approach to construct informative lower bounds to the impact of the technology stagnation on long-run inflation without relying on the exact Euler equation and some of the balanced growth path properties. By using the lower bounds, we find that inflation would be close to 0% or even negative without the technology stagnation. Moreover, the technology stagnation explains a sizable fraction of the observed slowdown in the real GDP and consumption growth. Our findings challenge the conventional view that Japan emerged from long-lasting deflation owing to the unconventional monetary policies. Finally, we apply our analysis to European countries and uncover the hidden stagflation there as well.

JEL Classification: E31, E43, E52, E58

1 Introduction

The Japanese economy suffered from low growth and low inflation since the stock market crash of 1990. Since then, the government has implemented a number of fiscal, monetary and deregulation policies to bring the economy out of stagnation. Especially since Governor Kuroda took office in 2013, the Bank of Japan (BOJ, the Japanese central bank) implemented an unprecedentedly

*We are grateful for continuous conversations with Ippei Fujiwara. We also acknowledge comments from Daisuke Adachi, Toni Braun, Masashi Hino, Hibiki Ichiue, Daisuke Ikeda, Mitsuru Katagiri, Shinnosuke Kikuchi, Tomohide Mineyama, Toshiaki Sekine, Satoshi Tanaka, Takashi Unayama, and Yuichiro Waki. We also thank Yukimi Ueda for the excellent research assistance.

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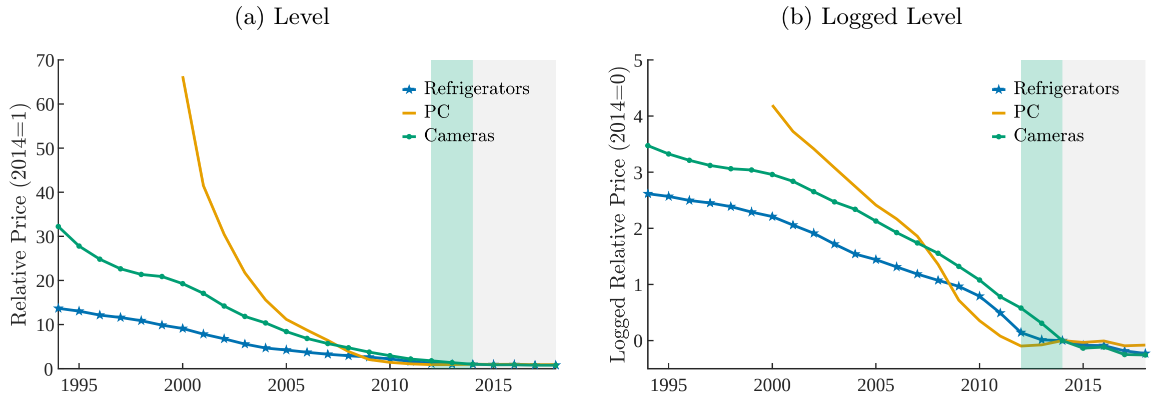
Figure 1: Relative Price of Typical Durable Goods



Notes. These individual price series are used to construct the headline CPI. The prices relative to the headline CPI are plotted. All price indices are normalized so that the values in 2014 are one.

aggressive policy framework known as the quantitative and qualitative easing (QQE). [1] Seemingly thanks to these efforts, there are signs that the economy has finally emerged from this long period of stagnation in the mid-2010s. Inflation has been steadily positive, finally ending the chronic deflation while it is below the target rate of 2%. Policy authorities (Bank of Japan (2016a) and Caldara et al. (2020)) and academia (Hausman and Wieland (2015) and Ito (2021)) have attributed this partial success to Abenomics accompanied by the strengthened unconventional monetary policies by the BOJ.

However, a glance at disaggregated price series in the CPI suggests that the rise in inflation may have been caused by reasons quite different from those mentioned above. The relative prices of typical durable consumption goods (refrigerators, personal computers, and cameras) in the CPI had steadily declined until 2011 (Figure 1). For example, the relative price of personal computers declined by more than 40% per year on average from 1994 to 2011, but declined by only about 2% annually since 2014. The decline in these relative prices slowed significantly about the same time that the implementation of the strengthened unconventional monetary policy began. Figure 1 suggests that these relative price movements may have caused the inflation in Japan to rise from 2014. Motivated by Figure 1, we aim to establish a connection among these relative price movements, the recent rise in inflation, and other macroeconomic facts about Japan.

We start by examining the movements of the deflators of the various subcategories that constitute aggregate inflation, and revealing that these deflators show the same pattern as that observed in the prices of individual goods above. We pay a special attention to the durable consumption goods and

[1] The BOJ has since further strengthened its monetary policy by introducing a negative interest rate on the reserves and yield curve control. Not only have short-term interest rates been kept extremely low but also long-term interest rates have been pushed down. The BOJ's asset purchase program to acquire a wide variety of financial assets including ETFs and REITs has also been expanded on an unprecedented scale.

information and communication technology (ICT) investment goods, which are hereafter referred to as durable and ICT goods, respectively. The deflators of these goods had alone been declining steadily, which also stopped falling since around 2014. These patterns have been observed in many developed countries including the US. Following Greenwood et al. (1997), we interpret these patterns as stagnation in technology improvement specific to the durable and ICT goods sectors, which we later refer to as the technology stagnation. To gain more credibility, we also examine the sectoral TFP sequences estimated by the EU-KLEMS. We find that these TFP estimates in many developed countries have stagnated as well and their estimates are significantly correlated with our measure of the technology stagnation. We investigate how these two negative shocks to durable and ICT goods have affected the Japanese economy.

In addition, we introduce various facts about the Japanese economy since 1990. It is well known that the Japanese economy has been growing at a low rate and experienced deflation since the 1990s (Hayashi and Prescott (2002)). The stagnation in the 1990s is known as the lost decade. Furthermore, economic growth remained weak even after the non-performing loan problem was resolved in the early 2000s. It is less known, however, that the Japanese economy has stagnated even further since 2014: both real GDP and consumption per effective worker have stagnated. This feature of the Japanese economy is puzzling especially if the QQE is effective (Hausman and Wieland (2015)). Interestingly, both nominal GDP and consumption growth rates increased during the same period. This means that the real side of the Japanese economy has stagnated, but the nominal side has not.

We then develop an accounting framework that explains these facts together, and quantify the impact of the technology stagnation on the aggregate inflation rate. We extend a standard growth model (Greenwood et al. (1997), Whelan (2003) and Gourio and Rognlie (2020)) by incorporating many consumption goods, investment goods, and a nominal bond. According to this model, the relative price of a good corresponds to the TFP level specific to the producer of that good. We use this relationship to estimate the slowdown in the TFP growth of durable and ICT goods, and confirm that the TFP growth rates of these goods have permanently declined since 2014.

We proceed to examine the relationship between the TFP growth rates and long-run inflation. As in standard monetary models, the real interest rate is determined by the supply side of the economy at the steady state.[2] The government in our model can achieve any target level of inflation by appropriately adjusting the nominal interest rate. An obvious implication of this is that even if the TFP growth rates decline (i.e., the real interest rate declines), the government can still hit the same inflation target by suitably adjusting the monetary policy. This feature of the model is no longer valid if the government cannot adjust its nominal interest rate appropriately, as is the case

[2]The words "steady state" and "balanced growth path" are used interchangeably unless it is confusing.

with the BOJ. In such a situation, a lower TFP growth induces a rise in long-run inflation. This is because if, for any reason, the nominal interest rate is fixed, a technology stagnation lowers the real interest rate, creating an inflationary pressure. We quantitatively analyze the extent to which this mechanism can explain the observed rise in inflation in Japan since 2014.

Our model allows us to derive how shocks to sector-specific TFP growth affect the long-run inflation rate at a steady state in a closed form. To derive the mapping, we use Euler equations and the steady state properties. However, it remains disputable whether these equilibrium conditions of the model can be taken literally. For example, although inter-temporal Euler equations are commonly used in macroeconomic analysis, their validity has been questioned by some studies (e.g. Canzoneri et al. (2007)). This concern is particularly problematic for us: it is far from obvious that the modest rise in inflation in Japan can be credibly explained if we rely on the questionable Euler equations at the steady state. Nor is it clear whether the economy can even be characterized by the steady state.

To address these concerns, we develop a new sign restriction approach inspired by the identification approach based on sign restrictions (Uhlig (2005)).[3] We replace the comparative statics based on the Euler equation and the steady state properties with weaker sign restrictions. Then, we construct informative lower bounds to the impact of negative technology shocks on long-run inflation with exploiting these sign restrictions. This procedure allows us to explicitly refrain from relying on the exact Euler equation and the steady state properties of the model. It is worth mentioning that the lower bound is informative only if the model has multiple consumption goods. When an economy has one good as in standard macroeconomic models, the lower bound only tells that negative technology shocks raise inflation, but does not tell the extent. Therefore, the multi-good feature of our model is essential for our analysis. Additionally, we impose more structure on the economy (i.e., use more equilibrium conditions), and obtain a tighter bound to the change in inflation induced by technology shocks. At this stage, we only assume some of the steady state properties, and replace the comparative statics based on the Euler equation with a sign restriction. This procedure allows us to clarify the implications of our assumptions and their impact on the change in aggregate inflation.

After estimating the sizes of the shocks to the durable and ICT goods sectors, we quantitatively analyze their effects on inflation in Japan since 2014. Even under the loose bound obtained with the weakest assumptions, the technology shocks to these two sectors account for more than 50% of the observed rise in inflation since 2014. Another way to look at this finding is that the inflation rate since 2014 would be less than 0.13% without the technology stagnation. If we use the tighter bound

[3] In econometrics and empirical industrial organization, a similar approach is used and called the partial identification approach. See Tamer (2010) for a survey.

based on stronger assumptions, the technology shocks account for around 80% of the observed rise in inflation. The inflation rate since 2014 would then be lower than -0.16%, and hence Japan would have been in the middle of deflation without the technology stagnation.

The model also predicts that the technology stagnation induces sizable stagnation in the real side of the economy. It lowers the growth rates of the real GDP and consumption per effective worker by 0.29% points and 0.93% points, which accounts for 70% and 60% of the observed slowdown in these growth rates respectively. Interestingly, our model shows that nominal GDP and consumption do not stagnate, which is consistent with one of the aforementioned feature of the Japanese economy.

Our findings have a natural policy implication for Japan. The rise in inflation in Japan since 2014 is often attributed to the unconventional monetary policies of the BOJ. The economy emerged from long-lasting deflation. Higher inflation is perceived as a good signal of the economy. Our findings challenge this conventional interpretation. We argue that the Japanese economy has experienced *hidden stagflation*: the prices have increased and both the real GDP and consumption have stagnated. Therefore, the recent rise in inflation is by no means a good signal of the economy.

Finally, to lend more credibility to our mechanism, we conduct two robustness exercises. First, we examine whether the Japanese firms have increased their market power. The recent literature points out that at least in the US, firms have increased their markup (Loecker et al. (2020) and Loecker and Eeckhout (2021)). Hence, an increase in some prices might not reflect a technology slowdown, and may be an indication of the increased market power. We show both sectoral and firm-level evidence that Japanese firms have not increased their markups. Second, we analyze the impact of technological stagnation on the inflation rates of European countries. Europe, like Japan, is arguably facing an effective lower bound constraint over the last decade. We apply our sign restriction approach to European countries and find that countries experiencing greater technological stagnation experience lower disinflation. Thus, we uncover that the hidden stagflation prevails in Europe as well.

Our paper contributes to the recent and ongoing debate on whether developed countries are in secular stagnation (Summers (2015) and Summers (2016)). In the literature, there is disagreement about the cause of the secular stagnation. On the one hand, Summers (2015), Summers (2016), and Eggertsson et al. (2019) argue that the cause is related to insufficient demand. On the other hand, Gordon (2015) and Ramey (2020) argue that the recent stagnation in the US is attributed to the slowdown in productivity growth.

Our study is also related to the literature analyzing the stagnation in Japan since 1990. Hayashi and Prescott (2002) conclude that Japan's stagnation in the 1990s was a stagnation in technological progress, not credit crunch. Aoki et al. (2017) propose an endogenous growth model which has multiple equilibria. They argue that the growth of Japanese economy stagnated because the economy switches to a self-perpetuating low productivity equilibrium. Caballero et al. (2008) argue that inefficient lending to so-called zombie firms caused a low productivity growth, and is the source of the stagnation in Japan. These lines of the past works can be interpreted as a micro-founded version of Hayashi and Prescott (2002). On the other hand, Illing et al. (2018) propose a model where the demand side of the economy plays a crucial role. In contrast to the aforementioned past works on the secular stagnation in the US or Japan, this study investigates the more recent and deepened stagnation in Japan since 2014. Moreover, unlike the existing research, our work contributes to the literature by connecting the stagnation in the real side of the economy to nominal phenomenon.

The rest of the paper is organized as follows. In Section 2, we introduce various facts about the Japanese economy since 1994. In Section 3, we develop the accounting model we use to quantify the effects of technology stagnation. Section 4 presents our theoretical results. In Section 5, we discuss how to map our model to data. We quantify the effect of TFP stagnation on the long-run inflation rate in Section 6. In Section 7 and Section 8, we examine the robustness of our empirical analysis. We conclude by discussing implications of our study for the monetary policy in Section 9.

2 Facts about Japanese Economy

In this section, we document several facts about nominal and real macroeconomic variables in Japan since 1994.[4] We pay particular attention to the change in the trends in these variables that occurred in the mid-2010s. The facts presented below indicate a possibility that Japan has experienced a slowdown in technology improvement in the last decade.

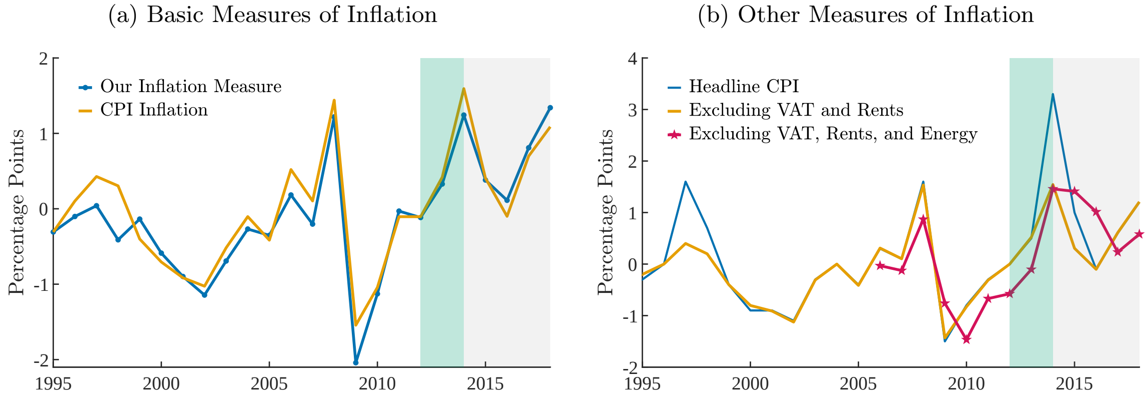
Fact 1. *Inflation in Japan had been negative until around 2011 and has been steadily positive since around 2014.*

We depict our main measure of inflation and various other measures of inflation in Japan in Figure 2a and 2b. As shown in these figures, Japan experienced prolonged deflation until around 2011. Japan emerged from it since around 2014. However, the inflation rate is still below the target level of 2%. This empirical pattern holds true no matter how inflation is measured (Figure 2b).

A conventional interpretation provided for the rise in inflation is that the BOJ's monetary policies pulled the economy out of deflation. To overcome deflation and low growth in the 1990s and 2000s, the BOJ implemented a variety of monetary policies. For example, the BOJ formally announced the adoption of an inflation target in January 2013, and introduced the QQE from April 2013. The inflation rate finally started to rise after the introduction of this policy, and has stayed steadily positive since around 2014. Due to this chronology, the rise in inflation is usually interpreted to be

[4] We study the economy since 1994 because of the data availability. In the latest national accounts, many series are only available from 1994.

Figure 2: Various Measures of Inflation



Notes. We use the growth rate of a version of chain-linked consumption deflator as our main measure of inflation. We exclude the effects of the value-added tax (VAT) and rents from these inflation rates. The inflation rate based on the consumption deflator is adjusted so that the initial inflation rate matches the CPI inflation rate. The headline CPI inflation rate in Figure 2b is the growth rate of the fixed-weight Laspeyres CPI of all goods and services. For a detailed explanation, see Section 5.1 and Appendix A.1 and A.3.

a result of the QQE. For instance, the BOJ itself attributes this rise in inflation to the QQE. In an official document, the BOJ says:

> QQE has lowered real interest rates by raising inflation expectations and pushing down nominal interest rates. Although the natural rate of interest has followed a downward trend, real interest rates have been well below the natural rate of interest, leading to an improvement in financial conditions. As a result, [the] economic activity and price developments improved, and Japan's economy is no longer in deflation, which is commonly defined as a sustained decline in prices. Bank of Japan (2016a, p.6)

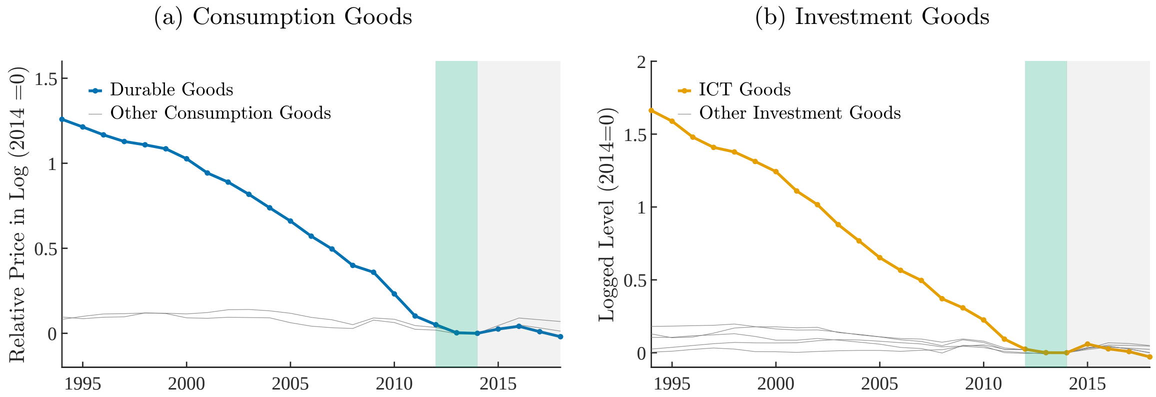
The same conclusion is drawn by Bernanke (2017) who says, "Kuroda's program of 'qualitative and quantitative easing' has had important benefits, including higher inflation and nominal GDP growth and tighter labor markets." Moreover, Hausman and Wieland (2014), Hausman and Wieland (2015), and Caldara et al. (2020) reach a similar conclusion, that is, the QQE generated positive inflation, but the inflation target was not fully achieved.

While there has been a positive assessment of the QQE by policymakers and economists, an intriguing yet unnoticed fact has also arisen over the same period in Japan.

Fact 2. *The relative prices of the durable and ICT goods declined steadily, and almost stopped declining since 2014.*

Figure 3a and 3b show the consumption and investment deflators by each subcategory, retrieved from the National Accounts of Japan (JSNA). Until 2011, the deflators of durable and ICT goods relative to the non-durable consumption deflator had been declining steadily. These relative prices

Figure 3: Growth Rate of Relative Prices



Notes. In JSNA, consumption is divided into 4 subcategories by durability, and investment is divided into 9 subcategories by asset. Each line in Figure 3 and Figure 3b represents the growth rate of the relative price of one of the 12 subcategories, where we exclude residential investment constituting one subcategory. See Section 5.1 and Appendix A for detailed explanations.

declined by -6.8% and -9.2% annually on average from 1994 to 2011. These declines are often regarded as measures of the technology improvement specific to the durable and ICT goods (Hulten (1992) and Greenwood et al. (1997)).

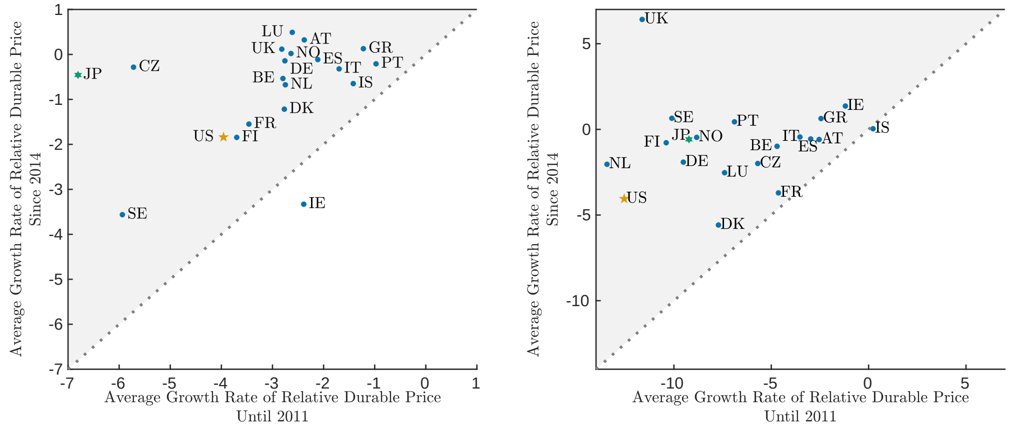
However, the decline in these relative prices began to weaken around 2012, and almost stopped since 2014. The period when these relative prices stopped falling matches almost exactly the period when the inflation in Japan began to rise. If the relative prices reflect technology improvement, Japan has experienced a slowdown in the technology improvement in these two sectors.

If the relative prices in Japan truly detect technological stagnation in those sectors, it is reasonable to expect that other developed countries have experienced similar phenomena as well. Indeed, the phenomenon that the relative prices of durable and ICT goods stopped declining or started declining slowly is commonly observed in many developed countries. In Figure 4a and 4b, we plot the average growth rates of the relative prices of durable and ICT goods until 2011 and since 2014. The horizontal axis depicts the average growth rate until 2011 and the vertical axis, the average growth rate since 2014. We can observe that most countries are in the shaded area, where the average growth rates of relative prices have risen. Moreover, many countries are concentrated around zero in the vertical direction, meaning that since 2014 the relative prices have stopped declining further or the decline significantly slowed down. For example, the relative price of the ICT goods in the US used to decline by more than 10% annually, but since 2014, it only declined by less than 5%.

Following Hulten (1992) and Greenwood et al. (1997), our interpretation of these facts about the relative prices is that they reflect their relative technology levels of the respective goods. Of course, the consumption and investment deflators contain the information about international trade and

Figure 4: Average Changes in Relative Prices

(a) Consumer Durable Goods (b) ICT Goods



Notes: We downloaded the annual national accounts data from OECD Stat to draw these figures. Each dot represents a country.

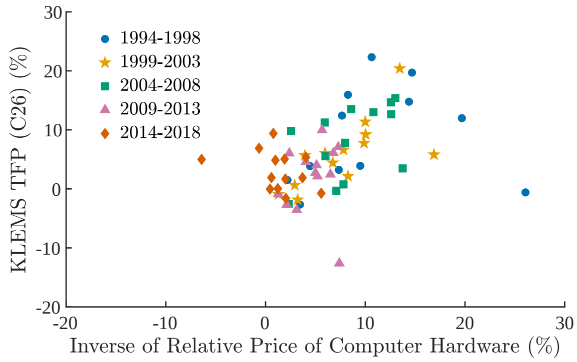
many other factors, nothing to do with technology per se.[5] Hence, there is a valid concern about our interpretation of the relative prices. To resolve this issue and assess the robustness of our interpretation, we compare our measures of the technology stagnation in ICT goods with the TFP estimated by the EU-KLEMS. The estimates of TFP growth by the EU-KLEMS are not derived from the changes in the relative prices of the final consumption or investment expenditure. Instead, the EU-KLMES begins by measuring the factor inputs and outputs.[6] By assuming that all markets are competitive and the production function satisfies the constant-returns-to-scale, the growth rates of sectoral TFP are obtained by growth accounting. Therefore, the estimates by the EU-KLEMS are not subject to the critique that our method relying on the relative prices faces.

We compare our measures of technology improvement in the ICT goods sector with the TFP in the EU-KLEMS of the sector closest to our ICT goods sector. We choose a sector called Computer, electronic and optical products (C26) from the EU-KLEMS. In Figure 5, we plot the average growth rate of technology improvement in the ICT goods sector over various periods. We compare our measure corresponding to the horizontal axis with one by the EU-KLEMS corresponding to the vertical axis. Note that both measures show that a technology improvement in the ICT goods sector exhibits stagnation. These two measures positively correlate with each other and a naive

[5] For example, one possibility is that the relative prices of these goods declined because the yen depreciated, not due to the technology stagnation (Bank of Japan (2016b)). Note that the depreciation of the yen from 2011 was temporary. From 2014 onwards, the nominal and the real effective exchange rates stopped depreciating. However, the relative prices did not start falling again. Therefore, it is impossible to explain the *growth* rates of the relative prices of the durable and ICT goods based on the depreciation of the yen. See Appendix B.1 for a detailed discussion on this issue.

[6] Indeed, various deflators are used for estimating real inputs and outputs. As such, these deflators play an implicit role.

Figure 5: Comparison with EU-KLEMS TFP



Notes: Each point represents the average growth rate over a given period for a given country. Since we use the KLEMS data, our sample includes Austria, Belgium, Czech Republic, Denmark, Finland, France, Italy, Japan, Netherlands, Sweden, the United Kingdom, and the United States. For Japan, we have more disaggregated sectoral TFP estimates. So, we choose a sector called "Electronic data processing machines, digital and analog computer equipment and accessories" for Japan.

regression tells that the slope is significant and positive. Therefore, our interpretation that Japan has experienced a technology stagnation in the ICT goods sector is robust.[7]

We can further check robustness for the case of Japan. The Japanese version of the EU-KLEMS is called the Japan Industry Productivity Database (JIP). The JIP provides industry-by-industry input-output (IO) tables. With this information, we can construct the TFP for the durable and ICT goods sectors.[8] In Table 1, we compute the average growth rates of these TFP and compare them with our measure of the technology stagnation. Both measures show significant slowdown in technology improvement in these sectors. The evidence is consistent with our interpretation, and we take the relative prices to be an accurate measure of the specific technological changes.

Now we present facts about the Japanese economy that are important inputs for disciplining our model and empirical analysis below.

Fact 3. *The relative share of the durable goods in nominal consumption has been stable whereas their relative prices have declined substantially.*

Figure 6a and 6b show the logged relative prices of consumption goods and the associated logged relative share with respect to the price of non-durable goods excluding food. As shown in Fact 2, the relative price of the durable goods has fallen rapidly and significantly. It fell by about 70% between 1995 and 2011. But the nominal shares of the consumer goods have remained almost unchanged over the period as shown in Figure 6b. Even after 2013, when the relative price of durable goods

[7]When the technology stagnation began varies somewhat from country to country. For example, in the United States, the technological improvement in ICT goods sector began to slow down around 2005, and clearly stagnated after 2010 compared to that over the period up to 2005.

[8]It is hard to construct the TFP for the durable goods sector based on the EU-KLEMS dataset. Precisely speaking, there are many sectors which produce both durable and ICT goods, and the EU-KLEMS does not provide compatible supply and use tables (SUT) or input-output (IO) tables for obtaining final good demands.

Table 1: Comparison with Japanese KLEMS TFP

	Our Measure		KLEMS Estimate	
Period	Durable	ICT	Durable	ICT
1994-2011	6.8%	9.2%	5.1%	8.3%
2014-2018	0.5%	0.6%	2.3%	−2.1%
Change	−6.4%	−8.6%	−2.8%	−10.4%

Notes: We aggregate the sectoral TFP growth rates based on value added estimated by the KLEMS to measure the TFP growth for durable and ICT goods sectors. We measure the TFP of the durable goods sector by aggregating the TFP growth rates of: Household electric appliances; Miscellaneous electrical machinery equipment; Image and audio equipment; Communication equipment; Electronic data processing machines, digital and analog computer equipment and accessories; Motor vehicles (including motor vehicles bodies) by using their weights in the consumption expenditure. To construct the TFP growth rate for ICT goods sector, we aggregate the TFP growth rates of: Image and audio equipment; Communication equipment; Electronic data processing machines, digital and analog computer equipment and accessories by using their weights in the investment expenditure. These aggregated TFP growth rates can also be obtained by aggregating the sectoral TFP growth rates based on the gross output by using appropriate weights which resemble the Domar weights.

stopped falling, the shares remained almost constant. This implies that the growth rate of real durable consumption has declined. These two graphs show that at this level of aggregation, the demand function is roughly characterized by the Cobb-Douglass form.

Fact 4. *Various nominal interest rates are stuck at zero or moved only a little in Japan.*

Figure 7a and 7b depict the various interest rates in Japan. The short-term policy interest rate has been near zero since 1997 and hardly moved. When the QQE policy was introduced in April 2013, the BOJ started to buy government debts with much longer maturity, which pushed down longer-term interest rates. Moreover, since the BOJ implemented the negative interest rate policy in January 2016, the interest rate for the ten-year government bond has sharply dropped and stayed close to zero.[9] Although the policy interest rates have been further lowered, the typical interest rates that the households in Japan face have not responded much. As shown in Figure 7b, both the deposit and housing loan interest rates have been constant.[10] The government has a limited scope to further lower the interest rates that households face as the transmission to the interest rates is limited.

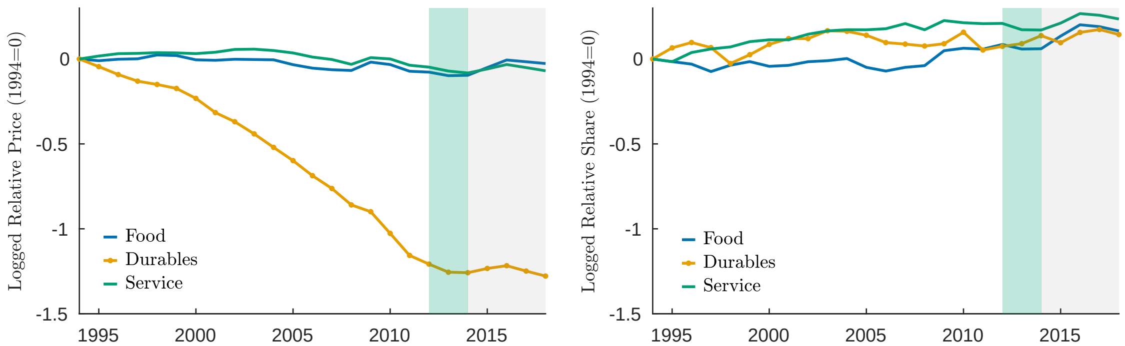
It is also politically difficult or nearly impossible for the BOJ to raise its nominal interest rate unless the inflation rate grows steadily to 2%. In January 2013, the BOJ issued a statement jointly

[9] For comparison, the interest rate on the ten-year US government bond after 2014 and before the COVID-19 crisis was more than 2%.

[10] See Hausman et al. (2019). They explore the reason why there was little pass-through to the housing loan interest rate.

Figure 6: Relative Prices and Relative Shares

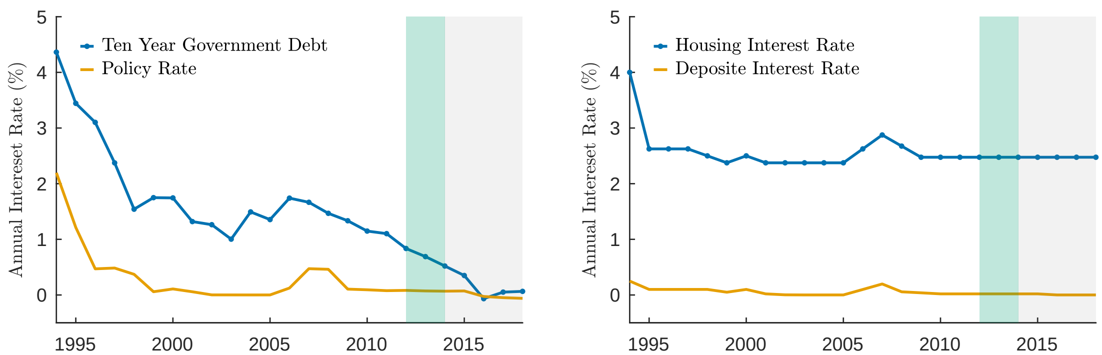
(a) Relative Prices (b) Relative Shares



Notes. We plot the logarithm of relative prices and relative shares with respect to the non-durable goods. The relative share is defined as a ratio of shares. We normalize each sequence so that its initial value is zero.

Figure 7: Various Interest Rates

(a) Policy and Government Debt Interest Rate (b) Housing and Deposit Interest Rates in Japan



Notes: We measure the housing interest rate by median rates of the floating interest rates offered by major banks. The data can be downloaded from BOJ's website.

with the government in which it promised to introduce an explicit price stability target and commit to achieve a sustainable and stable rate of inflation of 2% as soon as possible. Until this commitment is fulfilled, the BOJ will pursue monetary easing and cannot raise the nominal interest rates. The recent episode of inflation triggered by a combination of supply chain disruption due to COVID-19 and the war in Ukraine is a good example of how binding this commitment is. CPI inflation rate in April 2022 exceeded 2%, but the BOJ has explicitly stated that they are unlike the central banks in Europe and the US and insists that it is too early to even discuss tightening the monetary policy. Given these facts and examples, we conclude that the BOJ will not raise the nominal interest rates.

Fact 5. *Real GDP and consumption growth in Japan have weakened since around 2014, but the nominal GDP and consumption growth have not.*

This last fact is related to Fact 3 and the supply side of the economy. The real economy began

Table 2: Average Growth Rates

	GDP		Consumption	
Period	Real	Nominal	Real	Nominal
1994-2011	0.51%	-0.44%	0.63%	-0.10%
2014-2018	0.04%	1.19%	-0.71%	0.14%
Change	-0.48%	1.63%	-1.33%	0.24%

Notes. In this table, we show the average growth rates of GDP and consumption per effective worker. The sequence of the labor input is taken from the JIP.

to stagnate even further during the same period that the BOJ started implementing the QQE. Table 2 summarizes the information on the average growth rates of real GDP and consumption per effective worker.[11] From 1994 to 2011, the average growth rate of real GDP per effective worker was around 0.51%, but it almost stopped increasing since 2014. Similarly, the average growth rate of real consumption per effective worker used to be approximately 0.63%. Since 2014, the growth rate has stagnated and the average growth rate is approximately -0.71%.[12] This weakness of the real economy casts doubt about the conventional interpretation that Japan has emerged from 15 years of modest deflation thanks to the QQE policy. The weak consumption in Japan is also discussed in Hausman and Wieland (2015). They say that this slowdown in consumption since 2014 is puzzling especially because the BOJ's monetary policy successfully lifted the economy out of deflation.

Those familiar with the Japanese economy may question how much of an impact the value added tax (VAT) hike enacted in April 2014 has on this weakness. Hino (2021) estimates the impact of the VAT hike by calibrating his model to the Japanese economy, and shows the estimated consumption response to the VAT hike in Figure 16 of his paper. In the simulation in his study, the consumption level rises right before the implementation of the VAT hike, declines when the VAT hike is enacted, and converges to a new steady state in two years. This means that the negative effect of the VAT hike on the *growth* rate of consumption is concentrated in the year in which the hike is enacted. Thus, the average growth rate from 2015 was not pushed down by the VAT hike in 2014. We confirm that the average growth rate of real consumption since 2015 is -0.68%, which is still much lower than the average growth rate until 2011. Therefore, we conclude that the weak consumption is not attributed to the VAT hike in 2014.

[11] The same empirical pattern is observed in the real GDP and consumption per capita. The real variables have stagnated more than the corresponding nominal variables. In the model below, however, we do not model the labor supply decision. Hence our model can analyze the real GDP and consumption per effective worker, but not these variables per effective worker. This is why we choose to show the real GDP and consumption per effective worker.

[12] The average growth rate of real consumption per capita has also stagnated since 2014 and is around 0.2%.

The stagnation in real GDP and consumption is actually attributed to the rise in the associated deflators. In Table 2, we also display the average growth rates of nominal GDP and consumption over the same periods. Both the growth rates increased since 2014. The average growth rate of nominal consumption from 1994 to 2011 was -0.10%, and that since 2014 is 0.14%. Thus, the stagnation in real GDP and consumption comes from the fact that the prices of these goods have increased.

With these facts in mind, in the next section, we present an accounting model and show that the model is consistent with each of the facts presented in this section.

3 Accounting Model

In this section, we introduce a framework to analyze the effect of the technology stagnation on the recent rise in inflation in Japan. The model presented here is a generalization of the models by Greenwood et al. (1997), Whelan (2003), and Gourio and Rognlie (2020). We augment these models by introducing many durable and non-durable consumption goods, many investment goods, and nominal bond. We only consider a deterministic and discrete-time economy and its steady state properties (or balanced growth path).

3.1 Households

There is a representative household in this economy, and their utility function is

$$U = \sum_{t=0}^{\infty} \beta^t u\left(\prod_{i\in\mathcal{C}} D_{i,t}^{\gamma_i}\right) \quad \text{with } u\left(x\right) = \frac{1}{1-\sigma}x^{1-\sigma}, \tag{1}$$

where $D_{i,t}$ is the stock of consumption good i at date t, and $\mathcal{C}$ is the set of the subcategories of consumption goods such as food. We assume $\sum_{i\in\mathcal{C}}\gamma_i = 1$ and $\sigma \geq 1$.[13] The law of motion of the stock of consumption good i is

$$D_{i,t} = C_{i,t} + \left(1-\delta_i\right) D_{i,t-1}. \tag{2}$$

where $C_{i,t}$ is the total purchase of consumption good i, δ_i is the depreciation rate for good i and $D_{i,-1}$ is exogenously given. When δ_i is equal to one, good i becomes non-durable good. Otherwise, good i is a durable good. Let $P_{i,t}$ denote the price of consumption good i. We assume that there exists at least one non-durable good. Let i^* denote an index for the benchmark non-durable good.

The household can accumulate capital stocks and rent them to firms. Let $\mathcal{I}$ denote the set of the subcategories of investment goods. The investment goods and the corresponding capital stock

[13] This restriction on the elasticity of substitution (EIS) $1/\sigma$ is advocated by Havranek (2015). Also, Cashin and Unayama (2016) estimate the EIS for Japan, and find that the EIS is not significantly different from zero, but significantly less than 1. Their point estimate of the EIS is 0.21 so that $\sigma = 4.76$.

are indexed by $j \in \mathcal{I}$. The law of motion for capital stock of good $j \in \mathcal{I}$is given by

$$K_{j,t+1} = I_{j,t} + (1 - \delta_j) K_{j,t},$$

where δ_j is the depreciation rate for good j. The rental rate of good j is denoted by $r_{j,t}$. The household provides labor service inelastically to firms and obtain the labor income. The flow budget constraints are given by

$$\sum_{i \in \mathcal{C}} P_{i,t} C_{i,t} + \sum_{j \in \mathcal{I}} P_{j,t} I_{i,t} + B_{t+1} = \sum_{j \in \mathcal{I}} r_{j,t} K_{j,t} + w_t L_t + R_{t-1} B_t, \tag{3}$$

where L_t is the effective number of workers, w_t is the wage rate per effective unit, B_t is the government bond and R_t is the nominal interest rate. The household maximizes its utility (1) subject to the flow budget constraints (3) and the initial capital stocks, $(K_{j,0})_{j \in \mathcal{I}}$.

The optimality requires that the Euler equation and the transversality condition hold.[14] Since there are many consumption goods, the marginal utility takes a slightly different form, and is worth mentioning.

$$\frac{\partial u(D_t)}{\partial D_{i,t}} = \gamma_i \frac{D_t^{1-\sigma}}{D_{i,t}}, \tag{4}$$

where D_t denotes $\prod_{i \in \mathcal{C}} D_{i,t}^{\gamma_i}$. When there is only one good in this economy and it is non-durable, the marginal utility (4) boils down to $C_t^{-\sigma}$,where C_t is the non-durable consumption. In this case, all the Euler equations take the familiar forms.

3.2 Firms

There is a representative firm which produces benchmark non-durable good i^*. The representative firm has the production function,

$$Y_t = A_t \prod_{j \in \mathcal{I}} K_{j,t}^{\theta_j \alpha} L_t^{1-\alpha}, \tag{5}$$

where $K_{j,t}$ is the amount of capital stock of good j rented to the firm, L_t is the labor input and A_t represents the technology level, called economy-wide TFP. To avoid notational clutter, we often denote A_t by $A_{i^*,t}$. The representative firm buys capital and labor inputs in competitive factor markets, and $r_{j,t}$ and w_t denote the rental rate of good $j \in \mathcal{I}$ and the wage rate. The representative firm sells its products in competitive product markets. The maximization problem for the representative firm is given by

$$\max_{(K_{j,t})_{j \in \mathcal{I}}, L_t} \quad P_{i^*,t} A_t \prod_{j \in \mathcal{I}} K_{j,t}^{\theta_j \alpha} L_t^{1-\alpha} - \sum_{j \in \mathcal{I}} r_{j,t} K_{j,t} - w_t L_t.$$

[14]See Kamihigashi (2002) for a general treatment of the necessity of transversality condition.

We assume there is a linear technology to convert one unit of benchmark non-durable good i^* into $A_{n,t}$ unit of good $n \neq i^*$:

$$Y_{n,t} = A_{n,t} M_{n,t},$$

where $M_{n,t}$ is the amount of good i^* used as intermediate inputs for producing good n. For notational convenience, let $Y_{i^*,t}$ denote the amount of good i^* sold to the representative household. The linear technology function and the perfect competition imply that the price of good n relative to benchmark non-durable good i^*, denoted by $p_{n,t}$, corresponds to the inverse of the technology level specific to good n.

$$p_{n,t} = \frac{P_{n,t}}{P_{i^*,t}} = 1/A_{n,t}. \tag{6}$$

Equation (6) gives the direct interpretation of the changes in relative prices (Fact 2). Through the lens of this model, the decline of the relative price of good n reflects that the technology specific to sector n increases. Put differently, if the relative price of good n stops declining, then it implies that the technology specific to sector n stops improving. For notational simplicity, let $\mathbf{A}_t$ denote the vector, $(A_{n,t})_{n\in\mathcal{N}}$ and its vector of the growth rates $g_{\mathbf{A}_t}$, where $\mathcal{N}$ denote the union of the set $\mathcal{C}$ and $\mathcal{I}$.

3.3 Government

We assume that the government sets the logged nominal interest rate to some number, $\ln R_t = r$.[15] We are agnostic about the government's motive behind this monetary policy. Also the government does not issue any debt, $B_t = 0$. [16]

3.4 Equilibrium, Balanced Growth Path, and Macro Variables

A competitive equilibrium for this economy is defined as usual. Given $\mathbf{A}_t$ and r, a competitive equilibrium is a couple of the price system $(r_{j,t}, w_t, p_{n,t}, P_{n,t})$ and allocations $(C_{i,t}, D_{i,t}, I_{j,t}, K_{j,t}, Y_{n,t}, Y_t, L_t, B_t)$ such that: (1) given the prices, $(C_{i,t}, D_{i,t}, I_{j,t}, K_{j,t})$ solves the utility maximization problem; (2) given the prices, $(K_{j,t}, L_t)$ solves the profit maximization problem of firm i^* and; (3) equation (6) holds

[15] Another equivalent interpretation is that the government uses the Taylor rule satisfying the Taylor principle, and the economy gets stuck at the deflationary equilibrium.

[16] In Section 4.3, we explore implications of our model when the4.3 government uses the Taylor rule .

for all $n \in \mathcal{N}$ and; (4) all the market clearing conditions are satisfied:

$$\begin{aligned} Y_t &= \sum_{n \neq i^*} Y_{n,t}/A_{n,t} + Y_{i^*,t} \\ Y_{i,t} &= C_{i,t} \quad i \in \mathcal{C}, \quad Y_{j,t} = I_{j,t} \quad j \in \mathcal{I} \\ B_t &= 0. \end{aligned}$$

In the empirical analysis below, we focus our analysis on a *balanced growth path* (BGP) of the economy. We assume that $g_{\mathbf{A}_t}$, consisting of the growth rates of the sectoral and the economy-wide TFP, is time-invariant but the growth rates are not necessarily the same across sectors. A BGP is a particular type of a competitive equilibrium in which all the endogenous variables grow at constant, but not necessarily the same, rates. Let g_X denote the growth rate of variable X along the BGP. By allowing a slight abuse of notation, let g_{X_t} denote the growth rate of variable X at date t.

The equilibrium objects do not involve the real aggregate GDP and aggregate inflation, but sectoral output and prices. In the neoclassical growth model, there is only one good, and the sectoral output corresponds to the real GDP naturally. Since there are many goods in this economy, there does not exist such an obvious mapping to the real GDP, consumption, and other macroeconomic variables. We define these macroeconomic variables as the statistical agency of Japan defines.

Since all the firms other than good i^* firm do not generate any value added, the real GDP corresponds to Y_t. The growth rate of the aggregate consumption, denoted by g_{C_t}, is defined as the weighted average of the real consumption growth rates by using the (lagged) consumption shares:

$$g_{C_t} = \sum_{i \in \mathcal{C}} s_{i,t-1} g_{C_{i,t}}, \tag{7}$$

where $s_{i,t-1}$ is the nominal share of good i in total consumption at date $t-1$.

Similarly, we define the inflation rate as the statistical agency in Japan (and European countries) does. The inflation rate is the weighted average of the growth rates of the consumption goods prices by using the same weights $s_{i,t-1}$:

$$\pi_t = \sum_{i \in \mathcal{C}} s_{i,t-1} g_{P_{i,t}}. \tag{8}$$

4 Theoretical Results

In this section, we analyze how the technology permanent shocks on $g_{\mathbf{A}_t}$ affect the long-run inflation rate. To do so, we begin by deriving the BGP growth rates of real GDP and consumption. Our parametric assumptions allow us to derive them in a closed-form, which is a natural extension of the results obtained in Greenwood et al. (1997), Whelan (2003), and Gourio and Rognlie (2020).

We then proceed to examine the implication for aggregate inflation when the monetary policy is constrained in Section 4.2. Instead of relying on the full specification of the model presented in Section 3, we propose a method motivated by the sign restriction approach that allows us to construct informative bounds to the change in aggregate inflation induced by the negative technology shocks.

In the last subsection, we explore the implications for aggregate inflation when the monetary policy endogenously responds to the technology shocks.

4.1 Growth Rates of Real Variables Along the BGP[17]

Recall that our accounting model is an extension of the standard single good growth model. In the standard growth model, when the TFP growth increases by 1%, the growth rate of the GDP increases by more than 1% due to the capital deepening effect (or network effect). The strength of this capital deepening effect depends on the capital share α. When we have multiple consumption and investment goods as in our model, this result is naturally generalized as follows:

Proposition 1. *Along the BGP,*

$$g_Y = \frac{g_A}{1-\alpha} + \sum_{j\in\mathcal{I}} \frac{\alpha\theta_j}{1-\alpha} g_{A_j} + g_L \tag{9}$$

$$g_{Y_n} = g_{A_n} + \frac{g_A}{1-\alpha} + \sum_{j\in\mathcal{I}} \frac{\alpha\theta_j}{1-\alpha} g_{A_j} + g_L \quad n \neq i^* \tag{10}$$

$$g_C = \sum_{i\in\mathcal{C}_{-i^*}} s_i g_{A_i} + \frac{g_A}{1-\alpha} + \sum_{j\in\mathcal{I}} \frac{\alpha\theta_j}{1-\alpha} g_{A_j} + g_L, \tag{11}$$

where $\mathcal{C}_{-i^*} = \{i \in \mathcal{C} : i \neq i^*\}$ and s_i is the share of consumption good i in total nominal consumption along the BGP.[18]

Proof. For the proof for Proposition 1 and the expressions for the consumption and GDP shares, see Appendix C. □

Equation (9) consists of three effects: the direct effect; the capital deepening effect; and the scale effect of labor augmentation. To explain these effects, it is useful to rewrite equation (9) as

$$g_Y = \underbrace{g_A}_{\text{Direct Effect}} + \underbrace{\frac{1}{1-\alpha}\left[\alpha g_A + \sum_{j\in\mathcal{I}} \alpha\theta_j g_{A_j}\right]}_{\text{Capital Deepening Effect}} + \underbrace{g_L}_{\text{Scale Effect}}. \tag{12}$$

[17] In this section, we use the properties of the BGP and get an implication for aggregate inflation. For its full characterization, see Appendix C.

[18] See Proposition 2 for the expression of s_i along the BGP.

The direct effect represents the effect of how much the economy-wide TFP g_A raises the growth rate of real GDP at fixed factors of production. The direct effect corresponds to the first term in the RHS of equation (12). The capital-deepening effect represents how the TFP vector $g_{\mathbf{A}}$ indirectly affects the growth rate of the economy through endogenous capital accumulation. Suppose that the growth rate of TFP specific to investment good j increases by 1%. If the capital stock of good j accumulates more quickly due to the technology improvement, the output grows faster. The multiplicative, $\alpha\theta_j$, captures this effect, and corresponds to the output elasticity of capital stock of good j. The rise in the output spills over to all the other sectors, and increases all the capital stocks, inducing further increases of the output. This second-round effect on the output is

$$\alpha\theta_j \sum_{k\in\mathcal{I}} \alpha\theta_k = \alpha^2\theta_j.$$

The sum reflects the spillover effect from firm j. So, the cumulative effect corresponds to $\alpha\theta_j + \alpha^2\theta_j + \cdots = 1/(1-\alpha)\,\alpha\theta_j$. The parameters $\left\{\alpha, \{\theta_j\}_{j\in\mathcal{I}}\right\}$ govern the strength of these capital deepening effects. The larger the output elasticity with respect to capital stock of good j is, the greater the capital deepening effect. The last effect, g_L, simply comes from the fact that the economy has effectively more workers. The difference between equation (9) and (10) arises because the latter is affected by the technology progress specific to good n. The growth rate of the aggregate consumption is the weighted average of the sectoral output growth rates by using the nominal consumption shares $(s_i)_{\in\mathcal{C}}$ as weights.

Note that the parameters $\{\gamma_i\}_{i\in\mathcal{C}}$ in the utility function (1) do not appear at all in equation (11). This is because: the welfare-based price index, or the ideal price index, is not used for constructing the aggregate real consumption (recall the definition (7)) and; the supply side of the economy is determined independently of the demand side of the economy (along the BGP).

We use Proposition 1 to study how the permanent technology shocks on the growth rates of TFP $g_{\mathbf{A}_t}$ affect the economy. Let $\mathbf{d}g_{A_i}$ denote a negative shock reducing the growth rate of sector i's TFP and $\mathbf{d}g_{\mathbf{A}}$ denote the vector of the sectoral shocks, $\mathbf{d}g_{\mathbf{A}} = (\mathbf{d}g_{A_n})_{n\in\mathcal{N}}$. In this paper, the non-positive shocks $\mathbf{d}g_{\mathbf{A}} \leq 0$ is referred to as the technology shocks, simply the shocks, or the technology stagnation. Let $\mathbf{d}g_Y^{\text{Tech}}$, $\mathbf{d}g_{C_i}^{\text{Tech}}$, and $\mathbf{d}g_C^{\text{Tech}}$ denote the changes in the growth rates of GDP, consumption of good i and aggregate consumption induced by the technology shocks $\mathbf{d}g_{\mathbf{A}}$. It follows from Proposition 1 that

$$\mathbf{d}g_Y^{\text{Tech}} = \frac{\mathbf{d}g_A}{1-\alpha} + \sum_{j\in\mathcal{I}} \frac{\alpha\theta_j}{1-\alpha}\mathbf{d}g_{A_j} \tag{13}$$

$$\mathbf{d}g_{C_i}^{\text{Tech}} = \mathbf{d}g_{A_i} 1_{\{i\neq i^*\}} + \frac{\mathbf{d}g_A}{1-\alpha} + \sum_{j\in\mathcal{I}} \frac{\alpha\theta_j}{1-\alpha}\mathbf{d}g_{A_j} \tag{14}$$

$$\mathbf{d}g_C^{\text{Tech}} = \sum_{i\in\mathcal{C}_{-i^*}} s_i \mathbf{d}g_{A_i} + \frac{\mathbf{d}g_A}{1-\alpha} + \sum_{j\in\mathcal{I}} \frac{\alpha\theta_j}{1-\alpha}\mathbf{d}g_{A_j}, \tag{15}$$

where $1_{\{\cdot\}}$ is an indicator function which equals to one if the condition $\{\cdot\}$ is satisfied and zero otherwise. As Foerster et al. (2022) do, we ignore the effects that the technology shocks affect the consumption shares.

4.2 Bounding Aggregate Inflation by Sign Restriction

In standard monetary models, e.g. New-Keynesian models, or frictionless monetary models like ours, the government can achieve any target inflation rate in the long-run by appropriately adjusting the nominal interest rate. So, even if the economy experiences a negative shock which affects the real interest rate, the government can always neutralize the effect on inflation by an appropriate adjustment of the nominal interest rate. Such an adjustment becomes infeasible, for example, when the government faces the effective lower bound on the nominal interest rate. Or some form of political pressure makes it difficult for the central bank to change the nominal interest rate. Given the discussion after Fact 4 in Section 2, the constraint on the nominal interest rate is particularly relevant for Japan. When the nominal interest rate is not appropriately adjusted, both New-Keynesian models and frictionless monetary models imply that the long-run inflation rate would change if the economy experiences permanent shocks affecting the real interest rate. In this subsection, we quantify the effect of the negative shocks $\mathbf{d}g_{\mathbf{A}}$ on the long-run inflation rate based on our accounting model in Section (3).

Recall that the inflation rate is defined in equation (8), and it can be decomposed into two components:

$$\pi_t = \sum_{i\in\mathcal{C}_{-i^*}} s_{i,t-1} g_{p_{i,t}} + g_{P_{i^*,t}}. \tag{16}$$

The first term is the weighted average of the growth rates of the relative prices, and the second term $g_{P_{i^*,t}}$ is the inflation rate of the benchmark non-durable good i^*. The first term reflects the sectoral technology levels of the economy and is given exogenously in our model.

Equation (16) clarifies a possible disconnect between the relative prices and the aggregate inflation rate: even if the economy experiences the changes in the relative prices, $g_{p_{i,t}}$, their implication for aggregate inflation can be undone by the induced change in the non-durable inflation rate $g_{P_{i^*,t}}$. So, in order to obtain the implications for aggregate inflation, we need to know how the non-durable inflation rate, $g_{P_{i^*,t}}$, is determined in the equilibrium.

To begin with, note that the aggregate inflation rate (16) along the BGP can be written as

$$\pi = -\sum_{i \in \mathcal{C}_{-i^*}} s_i g_{A_i} + g_{P_{i^*}}. \tag{17}$$

Non-durable inflation $g_{P_{i^*}}$ is a function of monetary policy r and the TFP growth rates, $g_{\mathbf{A}}$.

$$g_{P_{i^*}} = g_{P_{i^*}}(r, g_{\mathbf{A}}).$$

The mapping $g_{P_{i^*}}(\cdot)$ is obtained by solving the Euler equation and the production functions along the BGP:

$$g_{C_{i^*}} + (\sigma - 1) \sum_{i \in \mathcal{C}} \gamma_i g_{C_i} = \ln \beta + r - g_{P_{i^*}} \tag{18}$$

$$g_{C_i} = g_{A_i} 1_{\{i \neq i^*\}} + \frac{g_A}{1-\alpha} + \sum_{i \in \mathcal{I}} \frac{\alpha \theta_i}{1-\alpha} g_{A_i} + g_L \quad \text{for all } i \in \mathcal{C}. \tag{19}$$

The Euler equation (18) connects the change in the growth rate of marginal utility with respect to non-durable good i^* with the change in the (particular) real interest rate, $r - g_{P_{i^*}}$. Unlike the standard single-good economy, the Euler equation has an additional term, $(\sigma - 1)\sum_{i \in \mathcal{C}} \gamma_i g_{C_i}$, which corresponds to the change in the growth rate of the composite good, D_t (see equation (4)). When the economy has a single good, then the LHS of equation (18) boils down to the usual expression, σg_C. On the other hand, by Proposition 1, the sectoral consumption growth rates is connected to the growth rates of the TFP $g_{\mathbf{A}}$.

The object of our interest is the increase of aggregate inflation induced by the negative technology shocks $\mathbf{d}g_{\mathbf{A}}$. Let $\mathbf{d}\pi^{\text{Tech}}$ denote such a change. Mathematically,

$$\mathbf{d}\pi^{\text{Tech}} = \sum_{n \in \mathcal{N}} \frac{\partial \pi}{\partial g_{A_n}} \mathbf{d}g_{A_n}. \tag{20}$$

It follows from equation (17) that the elasticity, $\partial \pi / \partial g_{A_n}$, consists of the three parts:[19]

$$\frac{\partial \pi}{\partial g_{A_n}} = -s_n 1_{\{n \in \mathcal{C}_{-i^*}\}} + \frac{\partial g_{P_{i^*}}}{\partial g_{A_n}} + \frac{\partial g_{P_{i^*}}}{\partial r} \frac{\partial r}{\partial g_{A_n}}. \tag{21}$$

The first term is the direct effect of the technology shock to sector n on aggregate inflation operating through the relative prices. As the indicator function shows, this direct effect is absent for non-durable consumption good i^*. The second term is the impact of technology shock g_{A_n} on non-durable good i^* inflation. This second effect is present because the shock lowers the growth rate of the economy and consequently the real interest rate, generating inflationary pressure holding other variables fixed. The third term represents the endogenous response of monetary policy. If the government can freely change the nominal interest rate, then the government can offset the impacts of the aforementioned effects by appropriately adjusting its nominal interest rate. So, the relative price movements induced by the shocks do not have *any* implications on aggregate inflation. This argument formally states the potential disconnect between the shocks and the aggregate inflation rate, and explains why previous studies rightly have not paid attention to changes in relative prices or the shocks.

Therefore, we need to restrict the monetary policy reactions in order to obtain the aggregate implication $\mathbf{d}\pi^{\text{Tech}}$. In particular, we make the assumption that the monetary policy does not react to the technology shocks:

$$\frac{\partial r}{\partial g_{A_n}} = 0. \tag{22}$$

This equality constraint is motivated by the current political situation that the BOJ has faced and the history of its actual monetary policy. As we will confirm shortly, the technology shocks induces higher inflation.[20] As explained in Section 2, the BOJ made the explicit commitment in the joint statement with the government to achieve 2% inflation in a sustainable and stable manner. Given this commitment, it is politically difficult or even impossible for the BOJ to raise the nominal interest rate unless the commitment is fulfilled. As long as sustainable and stable 2% inflation is not achieved, the BOJ cannot raise its nominal interest rate in response to the shocks. Also shown in Section (2), the BOJ has limited capacity to further lower the nominal rate. In 2014, the interest

[19]The literature finds that this parameter β might summarize the information of the underlying incompleteness of asset markets and idiosyncratic risks (Nakajima and Polemarchakis (2005), Braun et al. (2012), Werning (2015), and Debortoli and Gali (2022)). That is, β might endogenously react to the shocks in theory. As far as we know, we find no empirical papers which support that. Theoretically, Braun et al. (2012) provides a model where β fluctuates over time, but does not endogenously react to the technology shocks. So in our benchmark analysis, we implicitly assume that β does not endogenously respond to the technology shocks, $\partial \beta / g_{A_n} = 0$. Or, our argument below is still valid under a weaker assumption that $\partial \beta / \partial g_{A_n}$ is negative for all $n \in \mathcal{N}$.

[20]If the shocks are sufficiently large, then the shocks cause inflation to exceed the 2% inflation target. If this is a case, the BOJ would raise its nominal interest rate in order to fight against inflation. Both equality constraint (22) and inequality constraint, $\partial r / \partial g_{A_n} \leq 0$, are inappropriate assumptions for such cases. We confirm later that the shocks we identified from the data are not sufficiently large and do not cause such high inflation.

rate on long-term government bonds was already around 0.5%. These two consideration motivate us to impose equation (22). However, it can be argued that there is still room for the BOJ to ease monetary policy. The argument below goes through as long as the BOJ does not raise the nominal interest rate after seeing the shocks, $\partial r/\partial g_{A_n} \leq 0$. This inequality constraint alone accurately reflects the political constraint that the BOJ has faced. Only for avoiding notational clutter, we impose equality constraint (22).

Now using the implicit function theorem to the Euler equation (18) and the production function (19), we obtain[21]

$$\mathbf{d}\pi^{\text{Tech}} = \sum_{i \in \mathcal{C}_{-i^*}} s_i \left(-\mathbf{d}g_{A_i}\right) + \frac{-\mathbf{d}g_{A_{i^*}}}{1-\alpha} + \sigma \sum_{j \in \mathcal{I}} \frac{\alpha\theta_j \left(-\mathbf{d}g_{A_j}\right)}{1-\alpha} + (\sigma - 1) \sum_{i \in \mathcal{C}_{-i^*}} \gamma_i \left(-\mathbf{d}g_{A_i}\right). \tag{23}$$

Since the shocks $\mathbf{d}g_{\mathbf{A}}$ are weakly negative, the technology shocks induce the rise in the inflation, $\mathbf{d}\pi^{\text{Tech}} > 0$.[22] If the shocks are weakly positive $\mathbf{d}g_{\mathbf{A}} \geq 0$, then such shocks induce the decrease of the aggregate inflation. The first term in the RHS of equation (23) is again the effects operating through the relative prices. The other terms represent the effects operating through the change in the real interest rate due to the shocks.

Using equation (23), we can figure out the extent to which the technology shocks have contributed to the rise in inflation. It is tempting to do so, but there are valid concerns for this methodology. In order to derive equation (23), we need to take both the Euler equation (18) and some of the BGP properties (19) literally. There are a lot of skepticism over the two equations. The Euler equations might not predict the modest changes in inflation accurately. Or the assumption that the supply side of the economy is well-characterized by the BGP might be implausible. Also we need to have a precise estimate of the elasticity of intertemporal substitution (EIS) parameter $1/\sigma$, which is known to be difficult to estimate.[23] So, at least we need to be prudent about these assumptions and consequently their implication on aggregate inflation (23).

To address these concerns, we take a new sign restriction approach inspired by the identification approach based on the sign restrictions (Uhlig (2005)). We replace the comparative statics based on the two equations (18) and (19) with associated weaker sign restrictions. We begin our analysis under weaker assumptions, and obtain a prudent informative lower bound to the change in aggregate inflation. Then by imposing more structure, we obtain tighter bounds.

To obtain the most prudent bound, the comparative statics based on the two equations (18) and

[21] Notice that equation (23) holds for any positive value of σ.

[22] Since along the BGP, γ_i is smaller than s_i, $\mathbf{d}\pi^{\text{Tech}} > 0$ even if $\sigma \leq 1$.

[23] See Havranek (2015) and the papers analyzed in his meta analysis.

(19) are replaced by the following two sign restrictions:

$$\frac{\partial g_{C_i}}{\partial g_{A_n}} \geq 0 \tag{24}$$

$$\frac{\partial}{\partial g_{A_n}} \left(r - g_{P_{i^*}} \right) \geq 0. \tag{25}$$

The first sign restriction (24) says that the consumption growth rates increase as a positive shock to sector n occurs. This sign restriction is obviously satisfied in the full model (See Proposition 1). When consumption growth increases, the economy needs to incentivize the household to consume more. The second sign restriction (25) requires that the real interest rate increases if a positive shock. When σ is greater than or equal to one, this second restriction encourages the households to consume more rapidly and is satisfied in the full model too.[24] Put differently, we only take the qualitative features (i.e., the signs) of the comparative statics results based on equation (18) and (19).

Given the monetary policy restriction (22) and the sign restrictions (24) and (25) , we can obtain an informative lower bound to the change in inflation. It follows from equation (20) and (21) that

$$\mathbf{d}\pi^{\text{Tech}} = \sum_{i \in \mathcal{C}_{-i^*}} s_i \left(-\partial g_{A_i} \right) + \sum_{n \in \mathcal{N}} \frac{\partial g_{P_{i^*}}}{\partial g_{A_n}} \mathbf{d} g_{A_n} + \sum_{n \in \mathcal{N}} \frac{\partial g_{P_{i^*}}}{\partial r} \frac{\partial r}{\partial g_{A_n}} \mathbf{d} g_{A_n}.$$

Equation (22) implies that the last term of the RHS is zero, and the sign restriction (25) combined with equation (22) implies that the second term of the RHS is weakly positive. Thus the change in inflation induced the shocks $\mathbf{d}\pi^{\text{Tech}}$ is bounded from below by

$$\mathbf{d}\pi^{\text{Tech}} \geq \sum_{i \in \mathcal{C}_{-i^*}} s_i \left(-\mathbf{d} g_{A_i} \right) > 0. \tag{26}$$

The direct effects through the relative prices is determined independently of the demand side of the economy and monetary policy, and therefore give us the the lower bound to $\mathbf{d}\pi^{\text{Tech}}$.

It is worthwhile to mention that this lower bound (26) is only informative if there are many consumption goods in this economy. If the economy has a single consumption good (as in most macroeconomic models), then the relative price effects are absent. Then our sign restrictions merely imply that the shocks induce higher inflation, $\mathbf{d}\pi^{\text{Tech}} \geq 0$. Such an lower bound is uninformative and we cannot assess by using this bound whether the recent rise in inflation in Japan is attributed to the technology stagnation or not. So the multi-good feature of our model is qualitatively essential

[24] When σ is less than one, a positive technology shock might induce the decline of the growth rate of marginal utility. This arises because the technology shock affects the consumption growth rates differently. When $\sigma < 1$, it follows from equation (4) that the positive effect of the technology shock on non-durable good i^* is offset by the negative effect coming from the composite good growth, $(1 - \sigma)\, g_D$.

for our analysis.

Now we impose more structure on the economy, and obtain a tighter bound to $\mathbf{d}\pi^{\text{Tech}}$. In particular, we impose that the production along the BGP is characterized by equation (19), and apply the implicit function theorem to obtain the comparative statics, $\partial g_{C_{i^*}}/\partial g_{A_n}$. We replace the Euler equation (18) with the following sign restriction:

$$\frac{\partial}{\partial g_{A_n}}\left(r - g_{P_{i^*}}\right) \geq \frac{\partial}{\partial g_{A_n}} g_{C_{i^*}}. \tag{27}$$

Again this inequality is satisfied in the full model. The Euler equation (18) tells us the level of the real interest rate consistent with the given consumption growth rates. When the consumption growth rate increases by 1%, the economy incentivize the households to do so by raising the real interest rate by σ%. Since σ is greater than one, the real interest rate increases at least by the same amount of the increase of the consumption growth rate. This logic is the idea behind the sign restriction (27).

Using sign restriction (27) with equation (22) and (19), we obtain a tighter lower bound to $\mathbf{d}\pi^{\text{Tech}}$.

$$\mathbf{d}\pi^{\text{Tech}} \geq \sum_{i\in\mathcal{C}_{-i^*}} s_i\left(-\mathbf{d}g_{A_i}\right) + \frac{\left(-\mathbf{d}g_{A_{i^*}}\right)}{1-\alpha} + \sum_{j\in\mathcal{I}} \frac{\alpha\theta_j}{1-\alpha}\left(-\mathbf{d}g_{A_j}\right). \tag{28}$$

Compared to the loose lower bound (26), this lower bound has additional effects operating through the change in the real interest rate due to the shocks. These effects come from the additional assumption we made, the BGP property (19). With this additional assumption, we know the exact relation between consumption growth and the shocks, and exploit this property to get an further implication for the change in the real interest rate.

An immediate implication of these lower bounds is that we can bound the change in the growth rates of nominal consumption and GDP due to the technology shocks. Let $\mathbf{d}g_{NC}^{\text{Tech}}$ and $\mathbf{d}g_{NY}^{\text{Tech}}$ denote the changes in aggregate nominal consumption and GDP due to the technology shocks:

$$\mathbf{d}g_{NC}^{\text{Tech}} = \mathbf{d}g_{C}^{\text{Tech}} + \mathbf{d}\pi^{\text{Tech}}, \mathbf{d}g_{NY}^{\text{Tech}} = \mathbf{d}g_{Y}^{\text{Tech}} + \mathbf{d}g_{P_{i^*}}^{\text{Tech}}.$$

The weak sign restriction (24) sorely implies that both the aggregate real consumption and real GDP decline. The weak sign restrictions (24) and (25), however, cannot determine the signs of the aggregate nominal consumption and GDP. If we impose more structure and use the BGP property (15) and the tighter lower bound (28), then both the changes in nominal consumption and the GDP are both positive. So, our model predicts that the technology stagnation induces the stagnation in the real variables, but not the nominal variables. These implications are consistent with Fact 5.

4.3 Implication When The Monetary Policy Responds

The results in Section 4.2 are obtained under the assumption that the monetary policy is somehow constrained, (22). In this subsection, we quickly show that when the monetary policy endogenously responds to the shocks, then it is possible that long-run inflation raises, declines or does not change depending on the response. We demonstrate this point in a variant of our model where there is a single good in the economy.

Since the economy has a single good, the Euler equation and the production function take a simpler and standard form:

$$g_C = \frac{1}{1-\alpha} g_A$$
$$\sigma g_C = \ln \beta + r - \pi.$$

Suppose that the monetary policy takes the form of the Taylor rule, $r = \bar{r} + \phi (\pi - \pi^*)$, where π^* is the target inflation rate. Then the equilibrium inflation rate is

$$\pi = \pi^* + \frac{1}{(\phi - 1)} \left(\frac{\sigma g_A}{1-\alpha} + \pi^* - \ln \beta - \bar{r} \right). \tag{29}$$

Equation (29) implies that the government can choose the steady state nominal interest rate $\bar{r}$ so that the inflation rate at the steady state coincides with the target level π^*.

Suppose that there is a negative shock to the TFP, $\mathbf{d}g_A$ and the growth rate of the economy declines. We consider two monetary policy responses. First, consider the case where the monetary policy, i.e., $(\bar{r}, \phi, \pi^*)$, does not change. Then the technology-induced inflation $\mathbf{d}\pi^{\text{Tech}}$ is $\sigma / (1-\alpha)(\phi - 1)\, \mathbf{d}g_A$, which can be positive or negative depending on the coefficient ϕ. To get more insights, assume that ϕ is greater than one so that the Taylor principle is satisfied. Since the technology improvement slows down, consumption growth declines. As in our model, to incentivize lower consumption growth, the real interest rate needs to decline. Because the government raises the nominal interest rate more than inflation, the inflation rate must decline for the real interest rate to fall. So, we obtain the implication that the technology shock induces the fall of inflation. When ϕ is less than one, we get an opposite result.

Second, consider the case where the government endogenously respond to the shock $\mathbf{d}g_A$ by changing its intercept $\bar{r}$ of the monetary policy. In particular, if the government sets its intercept $\bar{r}$ as

$$\bar{r} = \frac{\sigma g_A}{1-\alpha} + \pi^* - \ln \beta,$$

then inflation will be π^* for any g_A. So, the implication for aggregate inflation π critically depends on the endogenous reactions by the government.[25]

5 Mapping Model to Data

In this section, we estimate the growth rates of sectoral TFP $g_{\mathbf{A}}$ by using our accounting model. We begin by introducing our datasets in Section 5.1 and proceed to show how we estimate of the TFP growth rates and the parameters necessary for the estimation in Section 5.2 and 5.3. In the last subsection, we provide an empirical counterpart of the shocks $\mathbf{d}g_{\mathbf{A}}$.

5.1 Preliminary

For our empirical analysis, we use publicly available data about Japan. Our main sources are 2018 annual report on the national account of Japan (JSNA) and the Japan Industry Productivity Database 2021 (JIP).[26] JIP is constructed to be explicitly compatible with the compilation method by the EU-KLEMS. So by construction, JIP is comparable to the EU-KLEMS dataset.

We use JSNA in order to construct set $\mathcal{C}$ and $\mathcal{I}$. Set $\mathcal{C}$ consists of: food; non-durable goods (excluding food); durable goods; and services (excluding imputed rents). JSNA has the information about these consumption deflators and nominal expenditures.[27] So, we let the empirical counterparts of these prices, $\{P_{n,t}\}_{n\in\mathcal{N}}$, be the corresponding consumption deflators reported in JSNA. We make an adjustment so that the effects of VAT hikes are excluded from the changes of the prices.[28] We also compute the shares in consumption $\{s_{i,t}\}_{i\in\mathcal{C}}$ based on the information in JSNA. Set $\mathcal{I}$ consists of: other buildings and structures (structures); transport equipment; ICT equipment; other equipment; defense equipment; cultivated biological resources; and Intellectual Property Products (IPP). Again, the empirical counterparts of these prices are the corresponding investment deflators. The shares in investment are also computed from the information in JSNA. Following Greenwood et al. (1997), we exclude housing and residential investment from our analysis.

The aggregate inflation rate is the weighted average of these prices by using the lagged shares in consumption. We make an additional adjustment so that the level of inflation rate of the initial observation matches with that of CPI. The adjustment is innocuous since the aggregate consumption deflator and CPI are almost identical up to a constant, and we are interested in the change in

[25] The monetary policy stance has implication for the transition dynamics too. We include a formal analysis for transition dynamics in Appendix D.

[26] JSNA is compiled based on SNA 2008 and we use the dataset of which benchmark year is 2011. While there are newer datasets with benchmark year 2015, we use this because the latest JIP database is compatible with the datasets of which benchmark year is 2011, not 2015. The 2018 annual report on JSNA can be downloaded from the following URL, `https://www.esri.cao.go.jp/en/sna/data/kakuhou/files/2018/2018annual_report_e.html`.

[27] See Appendix A for the detail of the construction of the consumption deflators.

[28] The Japanese government raised its VAT in 1997 and 2014 in our sample period. For the detail of our adjustment, see Appendix A.3.

inflation, not the level of inflation.

5.2 Backing Out TFP

Our model gives a direct method to estimate the sectoral TFP growth rates $g_{\mathbf{A}}$. The method is almost the same as one used in Greenwood et al. (1997) and Gourio and Rognlie (2020). In our model, the growth rate of the (aggregated) Solow residual corresponds to the growth rate of the aggregate TFP.

$$g_{Y_t} - \alpha \sum_{j \in \mathcal{I}} \theta_j g_{K_{j,t}} - (1-\alpha) g_{L_t} = g_{A_t}. \tag{30}$$

If the Solow residual is obtained, this equation gives the direct estimate of the economy-wide TFP growth rate, $(g_{A_t})_t$.

We can also back out the TFP growth rates, $\left(g_{A_{n,t}}\right)_{n \in \mathcal{C}_{-i^*}}$ by using the firms' optimality conditions. Recall that in a competitive equilibrium, the relative price of good n reflects the relative TFP, (6). Taking log-difference of equation (6), for all $n \neq i^*$,

$$g_{A_{n,t}} = -g_{p_{n,t}}. \tag{31}$$

Note that the growth rates of the relative prices, $\left(g_{p_{n,t}}\right)_{n \in \mathcal{N}}$, are observable. So, equation (31) allows us to estimate the sectoral TFP growth rates.

5.3 Parameter Estimation

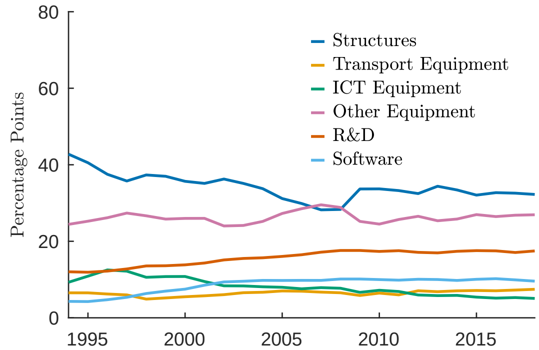
Now we discuss how we estimate the parameters $\left\{\alpha, \{\theta_j\}_{j \in \mathcal{I}}\right\}$, necessary input for obtaining (g_{A_t}) and using the bounds (26) and (28). Note that parameter α corresponds to the aggregate labor share for the economy. As JIP estimates an time-series of the aggregate labor share, we set the value of parameter α to its mean.

To estimate parameter θ_j, we use the methodology used in Gourio and Rognlie (2020). Gourio and Rognlie (2020) expresses θ_j in terms of observables by using the conditions which hold along the BGP.

$$\theta_j = \frac{s_I}{\alpha} s_j^I + \left(1 - \frac{s_I}{\alpha}\right) s_j^K, \tag{32}$$

where s_I is the aggregate investment share, s_i^K is the share of capital good i in the total nominal capital stock, and s_i^I is the share of capital good i in the total nominal investment. Since each term in the RHS of equation (32) has its empirical counterpart in JSNA, we can estimate a time-series of θ_j. Figure 8 depicts the time-series estimates of $\{\theta_j\}_{j \in \mathcal{I}}$. While initially the time-series estimates of

Figure 8: Time-Series Estimate of $(\theta_i)_{i\in\mathcal{I}}$



Notes: We only plot the time-series of θ_j for structure, transportation equipment, ICT equipment, other equipment, R&D, and Software. Other investment goods, defense equipment, cultivated assets, and other intellectual property product, have very small θ_j . For these goods, the time-series of θ_j is less than 3%.

θ_i are moving, but after 2005 the estimate get stabilized. We set the values of their average values to parameter $\{\theta_j\}_{j\in\mathcal{I}}$.

It is natural to expect that the parameters $(\gamma_i)_{i\in\mathcal{C}}$ is also estimated based on a similar method. Unfortunately, it is infeasible to apply the same method and estimate $(\gamma_i)_{i\in\mathcal{C}}$. Along the BGP, the parameter γ_i is not equal to a weighted average of observables. Instead, it equals to a weighted average of observable variables and unobserved variables. So, we cannot connect γ_i with observables as we can do for θ_j. However, we can still bound γ_i since it is a weighed average of variables including s_i and the weights are positive:

$$0 \leq \gamma_i \leq s_i. \tag{33}$$

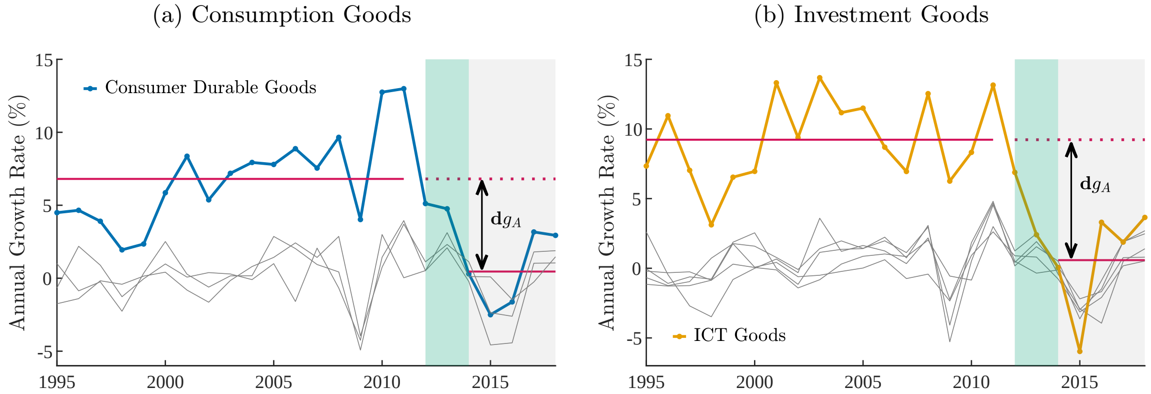
By using inequality (33) and equation (23), we can obtain another upper and lower bounds to $\mathbf{d}\pi^{\text{Tech}}$, which rely on both the exact form of the Euler equation (18) and the BGP properties (19).

5.4 Estimated Sectoral TFP

Since we obtain our estimate for $\left\{\alpha, \{\theta_j\}_{j\in\mathcal{I}}\right\}$, we can estimate the TFP growth rates $g_{\mathbf{A}_t}$. Figure 9 depicts these growth rates. With the exception of durable and ICT goods, the growth rates are at about the same level. They fluctuate over the business cycle, but there have been no changes in the average growth rates since 2014. On the other hand, the TFP growth rates of durable and ICT goods were higher than that of other goods until 2011. As documented in Table 1, the average growth rate is 6.8% for the durable goods and 9.2% for the ICT goods. Since 2011, their growth rates started to slow down and the average growth rates have stagnated. These growth rates were almost the same as that of other goods since 2014.

Motivated by these findings, we construct the empirical counterparts of the technology shocks

Figure 9: Growth Rate of TFP



Notes: Each solid line represents our estimate of the growth rate of TFP for a sector.

$\mathbf{d}g_{\mathbf{A}}$ as follows.

$$\mathbf{d}g_{A_i} = \begin{cases} \frac{1}{5}\sum_{t=2014}^{2018} g_{A_{i,t}} - \frac{1}{17}\sum_{t=1995}^{2011} g_{A_{i,t}} & i \in \{\text{ICT}, \text{Durables}\} \\ 0 & i \notin \{\text{ICT}, \text{Durables}\} \end{cases}.$$

That is, the negative technology shocks only occur in the durable goods and the ICT goods sectors, not others. The shocks are the differences between the average growth rates of these sectors since 2014 and their average growth rates up to 2011. Note that from equation (31), we can express the shocks in terms of the observables:

$$\mathbf{d}g_{A_i} = -\mathbf{d}g_{p_i} \tag{34}$$

where $\mathbf{d}g_{p_i}$ is

$$\mathbf{d}g_{p_i} = \begin{cases} -\frac{1}{5}\sum_{t=2014}^{2018} g_{p_{i,t}} + \frac{1}{17}\sum_{t=1995}^{2011} g_{p_{i,t}} & i \in \{\text{Durable}, \text{ICT}\} \\ 0 & i \notin \{\text{Durable}, \text{ICT}\} \end{cases}.$$

Because of the one-to-one mapping between $\mathbf{d}g_{A_i}$ and $\mathbf{d}g_{p_i}$ (34), we also call $\mathbf{d}g_{p_i}$ the technology shocks or simply the shocks.

6 Quantification

Now we are ready to quantify the impact of the technology stagnation in the consumer durable and ICT goods sectors on the Japanese economy. We use the various lower bounds derived in

Section (4.2) to quantify the impact on the aggregate inflation.[29] Then we examine how much the technology stagnation lowers the real consumption and GDP.

Using equation (34), the various bounds to the technology-induced inflation are expressed in terms of observables, estimated parameters, and the shocks:

$$s_{\text{Durable}}\mathbf{d}g_{p_{\text{Durable}}} \leq \mathbf{d}\pi^{\text{Tech}} < \infty \tag{35}$$

$$s_{c_{\text{Durable}}}\mathbf{d}g_{p_{\text{Durable}}} + \frac{\alpha\theta_{\text{ICT}}}{1-\alpha}\mathbf{d}g_{p_{\text{ICT}}} \leq \mathbf{d}\pi^{\text{Tech}} < \infty \tag{36}$$

$$s_{c_{\text{Durable}}}\mathbf{d}g_{p_{\text{Durable}}} + \sigma\frac{\alpha\theta_{\text{ICT}}}{1-\alpha}\mathbf{d}g_{p_{\text{ICT}}} \leq \mathbf{d}\pi^{\text{Tech}} \leq \sigma\left(s_{c_{\text{Durable}}}\mathbf{d}g_{p_{\text{Durable}}} + \frac{\alpha\theta_{\text{ICT}}}{1-\alpha}\mathbf{d}g_{p_{\text{ICT}}}\right). \tag{37}$$

Inequality (35) corresponds to the loose bound (26) obtained under the weaker assumptions. Inequality (36) is tighter than the loose bound (26) and corresponds to the bound (28). Last inequality (37) follows from equation (23), inequality (33), and equation (34). Note that the last bounds are qualitatively different from the others. To obtain the last inequality (37), we need to fully specify the model. The upper and lower bound in inequality (37) comes from the fact that it is hard to estimate γ_i, and the bounds to it (33) are only available.

There are three points worth mentioning about these bounds. First, the lower bound expression (35) resembles the contribution from the consumer durable goods to the aggregate inflation rate, which is $s_{c_{\text{Durable},t-1}} \times g_{P_{\text{Durable},t}}$. This simple contribution decomposition is frequently used among policymakers and market participants. But it is well-known that we cannot infer the implication for the aggregate inflation from such a decomposition exercise, as we discussed in Section 4.2. Our model provides a micro-foundation for a kind of the contribution decomposition method.[30]

Second, the lower bound (35) is only a function of readily available data. Most countries report the share of the durable goods s_{Durable} in consumption and the relative deflator of the durable goods $g_{p_{\text{Durable}}}$ in their national accounts. So, we can apply our method very easily to other countries. [31]

Finally, note that all the bounds (35), 36, and 37 are obtained under the assumption that the EIS is less than one, $1/\sigma \leq 1$. Havranek (2015) conducts a meta-analysis and argue that the EIS is at least less than 0.8, but Bansal and Yaron (2004) argues that the EIS is greater than one. We can still obtain a lower and upper bound even in this case by using equation (23). It follows from equation 23 and inequality 33 that when $\sigma \leq 1$, the lower (upper) bound to $\mathbf{d}\pi^{\text{Tech}}$corresponds to the upper (lower) bound in inequality 37.

[29] In principle, we can use the exact expression (23) too. But, it is hard to use equation (23) since we need to estimate $(\gamma_i)_{i\in\mathcal{C}}$.

[30] There is another subtle difference between our lower bound result (35) and the simple contribution decomposition. We use the lower bound (35) to quantify the effects of the permanent shocks on the aggregate inflation when the monetary policy is constrained, (22). The contribution decomposition analysis is typically used for analyzing monthly or quarterly fluctuation, especially in real-time assessments on economy by policymakers and market participants.

[31] In Section 8, we explore the implications of our analysis for European countries using inequality (35).

Table 3: Quantification of Technology Stagnation on rise in Inflation

Data	Type of Bounds to $\mathbf{d}\pi^{\text{Tech}}$	Lower Bound	Upper Bound
1.18% pt	Loose Bound	0.64% pt	∞
	Tight Bound	0.93% pt	∞
	Bounds Based on Full Model ($\sigma = 2$)	1.22% pt	1.86% pt
	Bounds Based on Full Model ($\sigma = 2/3$)	0.62% pt	0.83% pt

Notes: We set $\sigma = 2/3$ which is the number used in Bansal and Yaron (2004).

The results are summarized in Table 4. In Japan, the aggregate inflation rate increased by 1.18% points since 2014. We find that the depressed TFP for the durable goods and the ICT goods sectors greatly raise aggregate inflation in Japan. By using the loose bound (35), the model predicts that the shock to the durable goods sector alone increased inflation by 0.64% points. This direct effect operating through the relative price can explain more than half of the observed increase in inflation in Japan since 2014. If we impose more structure and use the tighter lower bound (36), then the model predicts that the technology shocks to the two sectors induce 0.93% points rise in inflation, which accounts for roughly 80 percent of the observed increase in aggregate inflation. If we fully specify the model and set $\sigma = 2$, then our model can almost fully account for the rise in inflation. Interestingly, even if we set $\sigma = 2/3$, the technology stagnation can account for more than half of the observed rise in inflation. But the upper bound in this case is much lower than that with $\sigma = 2$. But recall that these lower and upper bounds require further stronger assumptions so that their implications for aggregate inflation become less credible.

For better understanding of the magnitude of our results, let us compute the counter-factual inflation rate if TFP of the consumer durable and ICT goods did not stagnate since 2014 and kept their previous trends. The average observed inflation rate since 2014 is 0.77%. Without the technology shocks, our lower lower bound (35) implies that the aggregate inflation rate would be less than 0.13%. So it is barely positive. If we switch to stronger assumptions and use the tighter bound (36), then the aggregate inflation rate would be less than −0.16%. So, effectively the technology stagnation in these two sectors induce the positive inflation rate since 2014.

It is natural to wonder why these two tiny sectors have such a large impact on the aggregate inflation rate. Since we derive the lower bounds in closed forms, we can use these expressions to understand why so.

$$\underbrace{s_{\text{Durable}}}_{=0.1} \times \underbrace{\mathbf{d}g_{p_{\text{Durable}}}}_{=6.4\%} \leq \underbrace{\mathbf{d}\pi^{\text{Tech}}}_{=0.64\%} \tag{38}$$

$$\underbrace{s_{c_{\text{Durable}}}\mathbf{d}g_{p_{\text{Durable}}}}_{=0.64\%} + \underbrace{\frac{1}{1-\alpha}}_{=1.41} \times \underbrace{\alpha\theta_{\text{ICT}}}_{=0.02} \times \underbrace{\mathbf{d}g_{p_{\text{ICT}}}}_{=7.2\%} \leq \underbrace{\mathbf{d}\pi^{\text{Tech}}}_{=0.93\%}. \tag{39}$$

Table 4: Quantification on Consumption and GDP Growth Rates

	Quantification			Decomposition			
				Durable Goods		ICT Goods	
Variable	Data	Model	(Fraction)	(Weight)	($\mathbf{d}g_{p_{\text{Durable}}}$)	(Weight)	($\mathbf{d}g_{p_{\text{ICT}}}$)
$\mathbf{d}g_{C/L}$	-1.33% pt	-0.93% pt	(60%)	-0.64% pt		-0.29% pt	
				(0.10)	(6.4%)	(0.03)	(7.9%)
$\mathbf{d}g_{GDP/L}$	-0.48% pt	-0.29% pt	(70%)	0% pt		-0.29% pt	
				0%	0%	(0.03)	(7.2%)

These expressions give us a reason why the technology stagnation in these tiny sectors have large effect. This is because: the growth rates of sectoral TFP for the durable goods and the ICT goods substantially stagnated (6.4% and 7.2% respectively) and; the weights assigned to these two sectors are not negligible. Especially, the consumption share of durable goods is 10%, so that even the direct effect operating through relative prices has a sizable impact on the aggregate inflation rate.

Our model can also explain the slowdown of economic growth since 2014 in Japan. In particular, the model predicts the weak consumption. We use equation (15) and (13) to quantify the effects of the technology stagnation on these real variables:

$$
\begin{aligned}
\mathbf{d}g_{C/L}^{\text{Tech}} &= -s_{c_{\text{Durable}}}\mathbf{d}g_{p_{\text{Durable}}} - \frac{\alpha\theta_{\text{ICT}}}{1-\alpha}\mathbf{d}g_{p_{\text{ICT}}} \\
\mathbf{d}g_{GDP/L}^{\text{Tech}} &= -\frac{\alpha\theta_{\text{ICT}}}{1-\alpha}\mathbf{d}g_{p_{\text{ICT}}}.
\end{aligned}
$$

The result is summarized in Table 4. The model predicts that the technology stagnation in the durable goods and the ICT goods sectors explains the bulk fraction of the observed slowdown of these real variables. For example, the model can account for 60% of the stagnation in consumption growth.

Moreover, the model predicts that real consumption growth stagnates more than real GDP growth. This is because the negative technology shock arises in the durable goods sector, only affecting the real consumption adversely. So, the model can simultaneously explain: the rise in inflation; weak real consumption and; non-stagnation in nominal consumption. We provide a resolution to the consumption puzzle by Hausman and Wieland (2015).

Our findings have a policy implication for Japan. As we mentioned in Section 2, a conventional interpretation behind the recent rise in inflation is something to do with the monetary policies by the BOJ. Our model suggests a very different interpretation: the BOJ's monetary policy is effectively constrained, and Japan has experienced the rise in inflation induced by the technology stagnation.

This hidden stagflation is why Japan started experiencing inflation and the stagnation in the real consumption and GDP simultaneously. In other words, the fact that "Japan's economy is finally no longer in deflation" is largely attributed to stagflation.[32]

7 Rise of Markup

In this paper, we assume that all the markets are competitive, and the prices reflect the marginal costs. However, a number of recent studies have found rising markups, especially in the U.S. economy. In this section, we provide evidence on sectoral markups in Japan and introduce findings by the past research about the firm-level markups in Japan.

To discuss the implication of the markup, we extend our model by incorporating exogenous markup $\mu_{n,t}$ of sector n into the model. Then the growth rate of the relative price $n \neq i^*$ becomes

$$g_{p_{n,t}} = g_{\mu_{n,t}} - g_{A_{n,t}}.$$

So the relative price of good n would raise due to the increase of the markup of that sector or the technology stagnation. Put differently, our measure of the technology stagnation would be overestimated due to the rise of the markup.

To examine whether the sectoral markups have increased, we use the sectoral markups estimated by JIP. It measures the sectoral markup as follows:

$$\mu_{n,t} = \frac{\text{Gross Operating Surplus}_{n,t} + \text{Labor Cost}_{n,t} + \text{Intermediate Input Cost}_{n,t}}{\text{Capital Cost}_{n,t} + \text{Labor Cost}_{n,t} + \text{Intermediate Input Cost}_{n,t}}.$$

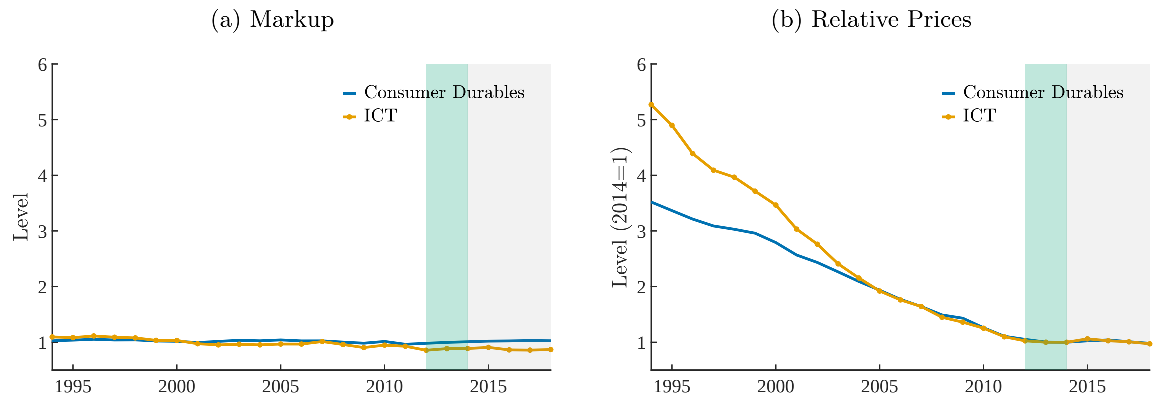
This measure of the sectoral markup accurately corresponds to the sectoral markup when, for example, the sectoral final good is a CES aggregation of the intermediate input and the intermediate good producers monopolistically supply these inputs, and have identical CES production function. We then aggregate $\mu_{n,t}$ in the two ways:

$$\mu_t^{\text{D}} = \sum_{n \in \tilde{\mathcal{C}}} \tilde{s}_{n,t}^{\text{D}} \mu_{n,t}, \quad \mu_t^{\text{ICT}} = \sum_{n \in \tilde{\mathcal{I}}} \tilde{s}_{n,t}^{\text{ICT}} \mu_{n,t}.$$

where $\tilde{\mathcal{C}}$ is the set of the sectors which produces durable goods, $\tilde{s}_{n,t}^{\text{D}}$ is the share of consumption good n in the total consumption among $\tilde{\mathcal{C}}$, and $\tilde{\mathcal{I}}$ is the set of the sectors which produces the ICT goods and $s_{n,t}^{\text{ICT}}$ is the share of gross fixed capital formation (GFCF) of good n in the total GFCF among $\tilde{\mathcal{I}}$. Note that $\mathcal{C}$ and $\mathcal{I}$ do not correspond to $\tilde{\mathcal{C}}$ and $\tilde{\mathcal{I}}$ because JIP has a more disaggregated

[32] The quote is from BOJ governor Kuroda's speech at the 2019 Michel Camdessus Central Banking Lecture, IMF. https://www.boj.or.jp/en/announcements/press/koen_2019/ko190723a.htm/

Figure 10: Markups and Relative Prices



classification. We construct $\tilde{\mathcal{C}}$ and $\tilde{\mathcal{I}}$ as follows. The set $\tilde{\mathcal{C}}$ consists of: household electric appliances; misc electronic equipment; image and audio equipment; communication equipment; electronic data processing machines, digital and analog computer equipment and accessories; and motor vehicles. The set $\mathcal{I}$ consists of: image and audio equipment; communication equipment and; electronic data processing machines, digital and analog computer equipment and accessories. The industry-by-industry IO table provides information about how much of the goods produced by each sector n is purchased for consumption of households and GFCF.[33] From the IO table, we can compute the weight $\left\{\tilde{s}^{\mathrm{D}}_{n,t}\right\}_{n\in\tilde{\mathcal{C}}}$ and $\left\{\tilde{s}^{\mathrm{ICT}}_{n,t}\right\}_{n\in\tilde{\mathcal{I}}}$ for each sector and date.

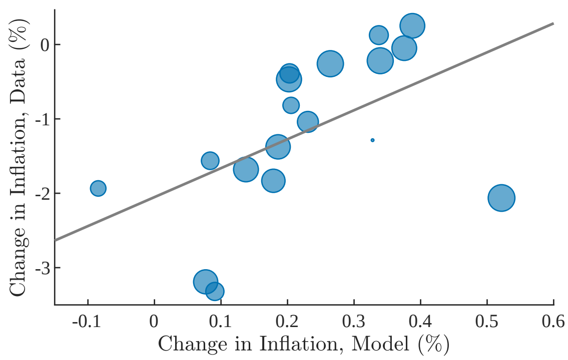
We plot the time-series of the markups and the relative prices of the consumer durable and ICT goods sectors in Figure 10a and Figure 10b. The markups of both sectors have remained virtually unchanged compared to the significant movement in the relative prices. So the sectoral markups estimated by JIP have not increased since 2014 to the extent that they explain the movement of the relative prices. A similar result is obtained in Nakamura and Ohashi (2019), which estimates the firm-level markups of Japanese firms. To estimate the firm-level markups, Nakamura and Ohashi (2019) apply the methodology used in Loecker and Warzynski (2016) and Loecker et al. (2020). They find that the overall manufacturing markup, and various other markups, have not increased. Given these evidence, we conclude that the movements of the sectoral markups are not the main driver for the raises in the relative prices of the consumer durable and the ICT goods.

8 Implication For European Countries

Since we argued that the technology stagnation is common across developed countries in Section 2, it is natural to expect that the other developed countries have experienced the same inflationary

[33]The industry-by-industry IO table is retrieved from this URL `https://www.rieti.go.jp/jp/database/JIP2021/data/jip2021_1-7.xlsx`, but only available in Japanese.

Figure 11: Implication For European Countries



Notes. The inflation rate for each country is the growth rate of the consumption deflator excluding imputed rent. The difference between the average growth rate until 2011 and the growth rate since 2014 is then calculated. The size of each bubble represents the size of a country. The solid line is the regression line.

pressure, especially when the low policy rates are prevalent. In this section, we explore the implication of our empirical exercise for other developed countries. In particular, we apply our sign restriction approach and estimate lower bounds (35) for European developed countries.

In Figure 11, we depict the observed changes in inflation and the changes in inflation induced by the technology stagnation in the durable goods, $s_{\text{Durable}}\mathbf{d}g_{p_{\text{Durable}}}$, for European developed countries. Note that inflation in almost all countries has declined since 2014 unlike Japan. But, Figure 11 shows that the countries with greater technology stagnation experienced smaller disinflation. The naive regression has the significant positive coefficient, 3.8. So, our model also implies that the European countries have experienced an inflationary pressure due to the technology stagnation in the durable goods, which generates heterogenous disinflation over the period. In other words, the model uncover the hidden stagflation in Europe too.

9 Conclusion

Japan has emerged from the long-lasting deflation during the 2010s. This emergence is considered to be, at least partially, a long-wanted success of the various QE policy. We challenge this conventional interpretation and propose the possibility of stagflation. We present evidence that Japan and other developed countries have experienced a slowdown of technology improvement in the durable goods and the ICT goods sectors. We quantify these technology stagnation through the lens of our model which extend Greenwood et al. (1997) into multiple consumption and investment goods setting. The key observation of this paper is that the changes in the growth rates of the relative prices can induce the change in the aggregate inflation rate when monetary policy is constrained. We develop a new sigh restriction approach inspired by Uhlig (2005) that how much the technology stagnation induces the rise in inflation without relying explicitly on Euler equation and some of the balanced growth path properties. We believe that our sign restriction approach to infer the informative lower bounds has potential use for many other macroeconomic research.

This study has the following implications for monetary policy. As we mentioned above, when monetary policy is constrained by the zero lower bound on the nominal interest rate, those channels that would otherwise have no effect can affect the long-run inflation rate. At one time, central banks cornered into the effective lower bound was considered to be a Japan-specific issue. However, since virtually all central banks in developed countries currently face or at least have to eye the possibility of limited capacities to lower their interest rates, technology stagnation would increase inflation of other countries in the future. It is important to understand the source of the rise in inflation.

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Appendix

A Data Appendix

A.1 Construction of Consumption Sequences

For consumption, we use the data in Supporting Table 11 and 12 of flow tables in JSNA.[34] We reclassify consumption expenditure into four subcategories. We call the first subcategory food, which corresponds to food and non-alcoholic beverages in Supporting Table 12. The second subcategory is called non-durable goods and contains non-durable goods and semi-durable goods in Supporting Table 11 excluding food which is the first subcategory. We call the third subcategory durable goods. This group corresponds to the durable goods in Supporting Table 11 itself. The final subcategory is called services, which contains all the consumption expenditures except the consumption goods in the other three subcategories and the imputed rent. Supporting Table 11 and 12 provide the enough information for constructing both nominal and real consumption by the above subcategories. We construct the real sequences by using the Tornqvist approximation method.

A.2 Construction of Investment Sequences

For investment, we use Supporting Table 14 of flow tables in JSNA. We classify the investment goods into nine subcategories: other buildings and structures; transport equipment; ICT equipment; other machinery and equipment; defense equipment; cultivated biological resources; research and development; mineral exploration and evaluation; and computer software. Supporting Table 14 itself provides the enough information for constructing nominal and real investment by the above subcategories.

A.3 VAT Adjustment to Inflation

The Japanese government raised the consumption tax in 1997 and 2014. These increases became effective on April 1st of these years. In order to exclude the effects of the VAT hikes from the prices of the consumption goods, we take the following two steps. First we assume that the VAT rises for all consumption goods except service goods. Let $P_{n,t}$ denote the (before-VAT) price level of good n at date t. Based on the assumption we can construct the after-VAT price level, denoted by $\tilde{P}_{n,t}$, of

[34] These supporting tables are retrieved from this link, https://www.esri.cao.go.jp/en/sna/data/kakuhou/files/2018/2018annual_report_e.html.

non-service good as

$$\tilde{P}_{n,t} = \begin{cases} \left[(1+\tau_{t-1})\frac{1}{4} + (1+\tau_t)\frac{3}{4}\right] P_{n,t} & t \in \{1997, 2014\} \\ (1+\tau_t) P_{n,t} & \text{otherwise} \end{cases},$$

where τ_t is the VAT rate of the last month in year t. The square bracket term, $[(1+\tau_{t-1})/4 + (1+\tau_t)3/4]$, reflects the fact that the VAT hike starts from April for both instances of hike, and the VAT of first quarter is τ_{t-1}, not τ_t in 1997.

The inflation rate excluding VAT coincides with the after VAT inflation rate for all $t \notin \{1997, 1998, 2014, 2015\}$:

$$\tilde{\pi}_{n,t} = \pi_{n,t}. \tag{40}$$

For $t \in \{1997, 2014\}$,

$$\tilde{\pi}_{n,t} = \ln \frac{\left((1+\tau_{t-1})\frac{1}{4} + (1+\tau_t)\frac{3}{4}\right)}{(1+\tau_{t-1})} + \pi_{n,t}, \tag{41}$$

and for $t \in \{1998, 2015\}$,

$$\tilde{\pi}_{n,t} = \ln \frac{(1+\tau_t)}{(1+\tau_{t-2})\frac{1}{4} + (1+\tau_{t-1})\frac{3}{4}} + \pi_{n,t} \tag{42}$$

Using equation (40), (41), and (42), we can compute the inflation rates adjusting the VAT hike $\pi_{n,t}$ for non-service goods.

Second, we use the aggregate inflation rates excluding the effects of the VAT hikes estimated by the Statistics Bureau of Japan in order to construct the VAT-adjusted inflation rate for service goods. Subtracting the VAT-adjusted inflation rate from the inflation rate before the VAT adjustment, we can extract the effect of the VAT hikes.[35] Let Δ_t denote the difference:

$$\sum_{n \in \mathcal{C}} s_{n,t}\tilde{\pi}_{n,t} - \sum_{n \in \mathcal{C}} s_{n,t}\pi_{n,t} = \Delta_t. \tag{43}$$

Since we already know the VAT-adjusted inflation rates for non-service goods, we can back out the inflation rate for the service sector by using the aggregate accounting constraint (43):

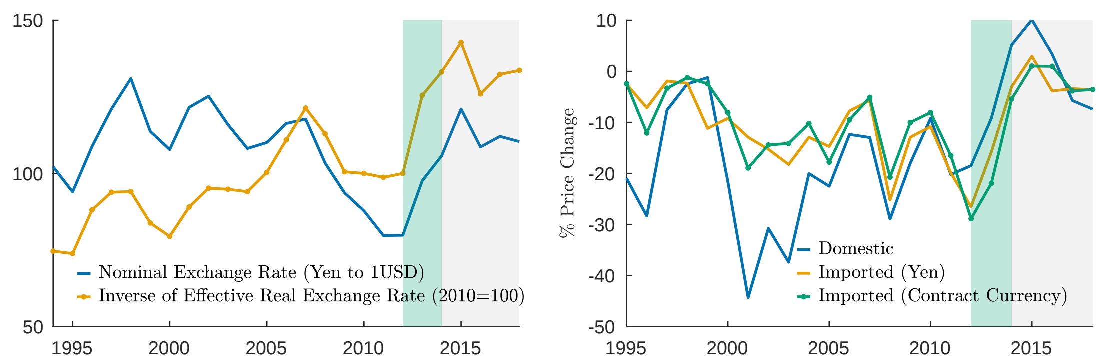
$$\pi_{\text{Service},t} = \frac{\sum_{n \in \mathcal{C}} s_{n,t}\tilde{\pi}_{n,t} - \sum_{n \notin \{\text{Service}\}} s_{n,t}\pi_{n,t} - \Delta_t}{s_{\text{Service},t}}.$$

B Additional Evidence

[35] Unfortunately, the data is only available in Japanese, and can be retrieved from this link.

Figure 12: Exchange Rates and Producer Prices

(a) Exchange Rates (b) Relative Price of Notebook Computer



Notes: In order to draw these figures, we use the latest PPIs of Japan (Corporate Goods Price Index). We download the various price data for notebook computers (PR01'PRCG15_2500850047).

B.1 Exchange Rate

As an additional evidence supporting our result, we discuss the possibility that the relative price might be affected by the depreciation of the yen. This view is actually supported by the BOJ. In an official report, the BOJ says that "developments in prices for goods -- especially for food products, durable goods, and clothes -- have continued to improve steadily, reflecting the resilient private consumption and the pass-through of the cost increases due to the depreciation of the yen." [Bank of Japan (2016b, p.25)] We argue that this view alone cannot explain the stagnation in the *growth* rate of relative prices of durable and ICT goods.

For the sake of our argument, we begin by plotting the nominal exchange rate against dollar (USD/JPY) and the inverse of the real effective exchange rate in Figure 12a and the growth rates of the inflation rates. Over the few years since 2012, both the nominal USD/JPY and real effective exchange rates have depreciated. During the same period, the relative price of desktop computers stopped falling shown in Figure 12b. Taking into account that many components of desktop computers are manufactured overseas, the weak yen is expected to have contributed to the increase in the price of personal computers. However, this temporary depreciation of the yen has not lasted long, neither in nominal exchange rates nor in real effective exchange rates since 2015. So, the temporal weak yen may explain a temporal rise in the price levels, but cannot explain the persistent rise in the growth rate of the relative prices of desktop computers.

C Characterization of BGP

Along the BGP in this paper, all the endogenous variables grow at constant rates. So it suffices to obtain the growth rates of them. We begin by deriving the equations which hold along the BGP in Lemma 1. Then we proceed to derive the growth rates of the endogenous variables. For notational convenience, let $\bar{g}_Z$ denote the exponent of g_Z. Recall that i^* denotes an index for one of the non-durable goods, which we choose as the benchmark.

Lemma 1. *The following equations are satisfied in an equilibrium:*

$$D_t^{1-\sigma}\frac{\gamma_{i^*}}{P_{i^*,t}C_{i^*,t}} = \gamma_i\frac{D_t^{1-\sigma}}{P_{i,t}D_{i,t}} + \beta D_{t+1}^{1-\sigma}\frac{\gamma_{i^*}}{P_{i^*,t+1}C_{i^*,t+1}}(1-\delta_i)\frac{P_{i,t+1}}{P_{i,t}} \tag{44}$$

$$1 = \beta\left(\frac{D_{t+1}}{D_t}\right)^{1-\sigma}\frac{P_{i^*,t}C_{i^*,t}}{P_{i^*,t+1}C_{i^*,t+1}}R_t \tag{45}$$

$$R_t = \left(\frac{r_{i,t+1}}{P_{i,t+1}} + 1 - \delta_i\right)\frac{P_{i,t+1}}{P_{i,t}} \quad i \in \mathcal{I} \tag{46}$$

$$\frac{r_{i,t}}{P_{i,t}} = \alpha\theta_i\frac{A_t}{p_{i,t}} \times \frac{\left(\prod_{b\in\mathcal{I}}K_{b,t}^{\theta_b}\right)^{\alpha}L_t^{1-\alpha}}{K_{i,t}} \quad i \in \mathcal{I}, n \in \mathcal{N} \tag{47}$$

$$\frac{w_t}{P_{i^*,t}} = (1-\alpha)\frac{A_t\left(\prod_{b\in\mathcal{I}}K_{b,t}^{\theta_b}\right)^{\alpha}L_t^{1-\alpha}}{L_t} \quad i \in \mathcal{I}, n \in \mathcal{N} \tag{48}$$

$$P_{n,t} = p_{n,t}P_{i^*,t} \quad n \in \mathcal{N} \tag{49}$$

where D_t is the composite good

$$D_t = \prod_{i\in\mathcal{C}} D_{i,t}^{\gamma_i}. \tag{50}$$

Proof. It is easy to show that the household's optimality conditions imply equations (44) and (45). The optimality conditions for the firms and the assumption of the particular functional form of the production function require that equations (47), (48) and (49). In an equilibrium, there are no arbitrage opportunities. So, equation (46) holds. □

Lemma 2. *Along a BGP, the sector i's share in total expenditure stays constant over time.*

Proof. The proof consists of three steps. First we show that the shares in nominal consumption stay constant along a BGP. Second, we show that the share of investment good $i \in \mathcal{I}$ in total expenditure stay constant too. In the last step, we show that the share of consumption good $i \in \mathcal{C}$ in total expenditure also stays constant.

Step 1. Using equation (44) and (49), we obtain

$$\frac{P_{i^*,t}C_{i^*,t}}{P_{i,t}D_{i,t}} = \frac{\gamma_{i^*}}{\gamma_i}\left[1 - \beta(1-\delta_i)\frac{1}{\bar{g}_{C_{i^*}}\bar{g}_D^{\sigma-1}}\frac{\bar{g}_{p_i}}{\bar{g}_{p_{i^*}}}\right]. \tag{51}$$

Along a BGP, the RHS of the above equation is constant and the consumption is proportional to the durable stock:

$$D_{i,t} = \left[1 - \frac{1-\delta_i}{\bar{g}_{D_i}}\right]^{-1} C_{i,t}. \tag{52}$$

Substituting this equation into equation (51), the ratios of consumption expenditure are time-invariant along a BGP. So the shares in nominal consumption stay constant along a BGP.

Step 2. The share of investment good $j \in \mathcal{I}$ in total expenditure is

$$\frac{P_{j,t}Y_{j,t}}{\sum_{n\in\mathcal{N}} P_{n,t}Y_{n,t}} = \frac{P_{j,t}\left(K_{j,t+1} - (1-\delta_j)K_{j,t}\right)}{\sum_{n\in\mathcal{N}} P_{n,t}Y_{n,t}}.$$

It is easy to show that the share of investment good $j \in \mathcal{I}$ can be written as follows:

$$\frac{P_{j,t}Y_{j,t}}{\sum_{n\in\mathcal{N}} P_{n,t}Y_{n,t}} = \alpha\theta_j\left(\bar{g}_{K_j} - (1-\delta_j)\right) \times \frac{P_{j,t}}{r_{j,t}}. \tag{53}$$

We use the fact that the production function is Cobb-Douglass. It follows from equation equation (45) and (46) that the rental rate divided by the corresponding output price stays constant along the BGP. So the share of investment good $j \in \mathcal{I}$ is constant.

Step 3. We already have established that the share of investment good $j \in \mathcal{I}$ in total expenditure is constant. So, it suffices to show that the share of consumption good $i \in \mathcal{C}$ in expenditure is constant. To see that, note that the share of consumption good i can be written as follows:

$$\frac{P_{i,t}C_{i,t}}{\sum_{n\in\mathcal{N}} P_{n,t}Y_{n,t}} = \frac{P_{i,t}C_{i,t}}{\sum_{i\in\mathcal{C}} P_{i,t}C_{i,t}} \times \left(1 - \frac{\sum_{j\in\mathcal{I}} p_{j,t}Y_{j,t}}{\sum_{n\in\mathcal{N}} p_{n,t}Y_{n,t}}\right).$$

Since the share of good i in total consumption is time-invariant (Step 1), and the shares of investment good j in value added are also time-invariant. So, the share of consumption good i in expenditure is time-invariant along a BGP. □

Now we show that there exists a unique BGP and we characterize the growth rates of the endogenous variables along the BGP in the following proposition.

Proposition 2. *Suppose the government sets its logged nominal interest rate to r. Then along the*

BGP, the growth rates of the endogenous variables are given by

$$g_{K_j} = -g_{p_j} + \frac{1}{1-\alpha} g_A + \frac{1}{1-\alpha} \sum_{j \in \mathcal{I}} \alpha\theta_j \left(-g_{p_j}\right) + g_L \tag{54}$$

$$g_Y = \frac{1}{1-\alpha} g_{A_{i^*}} - \sum_{j \in \mathcal{I}} \frac{\alpha\theta_j}{1-\alpha} g_{p_j} + g_L \tag{55}$$

$$g_{Y_n} = -g_{p_n} + \frac{1}{1-\alpha} g_A + \frac{1}{1-\alpha} \sum_{j \in \mathcal{I}} \alpha\theta_j \left(-g_{p_j}\right) + g_L \tag{56}$$

$$g_C = -\sum s_i g_{p_i} + \frac{1}{1-\alpha} g_A + \frac{1}{1-\alpha} \sum_{j \in \mathcal{I}} \alpha\theta_j \left(-g_{p_j}\right) + g_L \tag{57}$$

$$g_D = -\sum \gamma_i g_{p_i} + \frac{1}{1-\alpha} g_A + \frac{1}{1-\alpha} \sum_{j \in \mathcal{I}} \alpha\theta_j \left(-g_{p_j}\right) + g_L \tag{58}$$

$$\pi = \ln\beta - (\sigma - 1)\, g_D - g_C + r. \tag{59}$$

$$g_w = \ln\beta + r - g_L - (\sigma - 1)\, g_D \tag{60}$$

$$g_w - g_{P_{i^*}} = \frac{1}{1-\alpha} g_A - \frac{\alpha}{1-\alpha} \sum_{j \in \mathcal{I}} \theta_j g_{p_j} \tag{61}$$

where s_i is the share of consumption good i in nominal consumption, which is expressed in terms of the exogenous variables along the BGP.

Proof. Recall the rental rate of investment good i divided by the corresponding price is time-invariant. So taking log-difference of equation (47) and using equation (49) we obtain

$$g_A - g_{p_j} + \alpha \sum_{j \in \mathcal{I}} \theta_j g_{k_j} - g_{k_j} = 0, \tag{62}$$

where k_j is the growth rate of capital stock per effective worker. Multiplying θ_j on both sides of equation (62) and taking the sum over $j \in \mathcal{I}$, the following equation holds:

$$\sum_{j \in \mathcal{I}} \theta_j g_{k_j} = \frac{1}{1-\alpha} \left(g_{A_{i^*}} - \sum_{j \in \mathcal{I}} \theta_j g_{p_j} \right). \tag{63}$$

Substituting this equation into (62), we obtain equation (54). Using equation (63), the growth rate of real GDP is

$$g_Y = g_{A_{i^*}} + \alpha \sum_{j \in \mathcal{I}} \theta_j g_{k_j} + g_L = \frac{1}{1-\alpha} g_{A_{i^*}} - \sum_{j \in \mathcal{I}} \frac{\alpha\theta_j}{1-\alpha} g_{p_j} + g_L.$$

From this equation, we can drive the growth rates of sectoral output. Since the nominal shares are time-invariant,

$$g_{p_n} + g_{Y_n} = g_Y.$$

Substituting equation (63) into the above equation, we obtain equation (56). Equation (57) and (58) follow from equation (56) and their definitions (7) and (50).

We move on to the derivation of the inflation rate. Taking logarithm of equation (45), we obtain

$$0 = \ln\beta + (1-\sigma)\, g_D - g_{P_{i^*}} - g_{C_{i^*}} + r$$

Since the shares in nominal consumption are time-invariant, the growth rates of the consumption expenditures $p_i C_i$ are equalized. So,

$$0 = \ln\beta + (1-\sigma)\, g_D - g_{P_i} - g_{C_i} + r. \tag{64}$$

Multiplying s_i on both sides of equation (64) and taking sum over i, the inflation rate π is

$$\pi = \ln\beta - (\sigma-1)\, g_D - g_C + r. \tag{65}$$

Finally we can derive the growth rate of the nominal wage along a BGP. Using equations (63) and taking log-difference of equation (48),

$$g_w - g_{P_{i^*}} = g_A + \alpha \sum_{j\in\mathcal{I}} \theta_j g_{k_j} = \frac{1}{1-\alpha} g_A - \frac{\alpha}{1-\alpha} \sum_{j\in\mathcal{I}} \theta_j g_{p_j}. \tag{66}$$

Note that the following equation holds as an accounting identity:

$$\pi = \sum_{i\in\mathcal{C}} s_i g_{p_i} + g_{P_{i^*}}. \tag{67}$$

From equation (66), (67), (2a) and 57, it follows that the real wage along the BGP is

$$g_w = \frac{1}{1-\alpha} g_A - \frac{\alpha}{1-\alpha} \sum_{j\in\mathcal{I}} \theta_j g_{p_j} + g_{P_{i^*}} = \ln\beta + r - g_L - (\sigma-1)\, g_D.$$

We have established Proposition 2. □

D Transition Dynamics

We analyze two popular macroeconomic models: three equation NK model and; its frictionless limit model (or so-called frictionless RBC model) for a expositional reason. Strictly speaking, Fact 2 implies the stagnation in technology specific to ICT and durable goods, not a single economy-wide TFP as in three equation NK model. However, the NK model with capital behaves similarly to the conventional three equation NK model. So, instead of working with the NK model with capital, we decide to study a simpler version of it.

For each model, we study the perfect foresight impulse response functions with respect to a negative shock on the growth rate of an economy-wide TFP. We assume that the BOJ does not have a room to change the monetary policy rule against this negative shock, motivated by Fact 4. So, effectively the interest rate is pegged. We investigate whether the impulse response functions of the two models can generate patterns which are consistent with the Facts presented above.

D.1 NK Model

Since the NK model is now standard, we begin by positing the equilibrium system directly. [36] As mentioned above, the linearized equilibrium system is characterized by the three equations; the Euler equation (or so-called Dynamic IS curve); the Philips curve; and the exogenous process for the growth rate of the TFP.

We can write the linearized Euler equation as

$$x_t = x_{t+1} - \left[(r_t - \pi_{t+1}) - r^*_{t+1}\right], \tag{68}$$

where x_t is the output gap,[37] r_t is the nominal interest rate, $\pi_{t+1} = p_{t+1} - p_t$ is the inflation rate at date $t+1$, and r^*_{t+1} is the natural rate of interest at date $t+1$. We assume that the government sets its nominal interest rate based on the Taylor rule: $r_t = \phi \pi_t$. We consider the two extreme cases: the Taylor principle $(\phi > 1)$ and; the pegged interest rate $(\phi = 0)$. The natural rate of interest at date $t+1$ is given by

$$r^*_{t+1} = \mu_{t+1} - \mu_{old},$$

where μ_{t+1} is the growth rate of TFP at date $t+1$, and μ_{old} is the growth rate of TFP at the old steady state. Note that the NK model here can handle non-stationary environment.

The Philips curve links inflation at date t and the output gap at date t:

$$\pi_t = \kappa x_t + \beta \pi_{t+1},$$

where $\kappa > 0$ is an exogenous parameter, and often referred to as the slope of the Philips curve. For a fixed inflation rate at date $t+1$, the Philips curve implies that increased economic activity (higher

[36] For a derivation, see Gali (2015).
[37] In this environment, the output gap corresponds to the employment rate.

output gap x_t) leads higher inflation. This is because to provide more goods to the economy, the real wage needs to rise to incentivize households to work more, leading an increase in inflation at date t.

The last equation is the law of motion for the growth rate of TFP. Before date $t = 1$, the economy is assumed to be at its old steady state, and the inflation rate is assumed to be the target level, zero. At date 1, the economy suddenly experienced a negative shock, and the growth rate of the TFP is given by the following sequence:

$$\mu_t = \begin{cases} \mu_{old} & t \leq 0 \\ (1-\rho)\,\mu_{new} + \rho\mu_{t-1} & 1 \leq t < T \\ \mu_{new} & t \geq T \end{cases}, \tag{69}$$

where μ_{new} is the growth rate at the new steady state, and the shock reaches to the new steady state value from T. Following the practical equilibrium selection, we assume that the economy goes to the new steady state from date $t = T$. Also see Angeletos and Lian (2022) for a theoretical foundation.

Note that at the new steady state, the output gap and inflation are given by

$$x_{new} = \frac{1}{\kappa}(1-\beta)\frac{\mu_{new}-\mu_{old}}{\phi-1}, \quad \pi_{new} = \frac{\mu_{new}-\mu_{old}}{\phi-1}. \tag{70}$$

When the Taylor principle is satisfied, then the inflation rate at the new steady state is lower than the target level, and the output gap becomes negative. When the nominal interest rate is pegged ($\phi = 0$), the inflation rate at the new steady state will be higher. This steady state result is a formal version of the argument in Section 4.2.

It is known that a negative (transitory) TFP shock is expansionary when the interest rate is pegged.[38] The temporal decline of TFP implies that to supply a certain amount of goods, the economy needs to incentivize households to work more, leading higher inflation. Since the nominal interest rate does not respond, the real interest rate declines, which stimulates demand. [39]

On the other hand, in the case of a negative permanent shock on the growth rate of TFP, which is our focus, it leads to the opposite results. Because of our equilibrium selection, we can solve the model in a closed-form. More specifically, we know that at date T, the economy reaches to the new steady state characterized by equation (70). So, we can solve the equilibrium system backward from

[38] See Wieland (2019) and the papers cited by him.

[39] See Farhi and Werning (2016) for a general analysis of this kind.

date T.

$$
\begin{aligned}
x_t &= x_{t+1} - \left[(\phi \pi_t - \pi_{t+1}) - (\mu_{t+1} - \mu_{old})\right] \\
\pi_t &= \kappa x_t + \beta \pi_{t+1}.
\end{aligned}
$$

It is easy to verify that the solution takes the following form:

$$
\begin{aligned}
x_t - x_{new} &= \frac{1-\beta\rho}{\left[(1-\beta\rho)(1-\rho) + \kappa(\phi-\rho)\right]} (\mu_{t+1} - \mu_{new}) \\
\pi_t - \pi_{new} &= \frac{\kappa}{\left[(1-\beta\rho)(1-\rho) + \kappa(\phi-\rho)\right]} (\mu_{t+1} - \mu_{new}).
\end{aligned}
$$

Note that both coefficients are positive if the monetary policy responds to the inflation rate sufficiently strongly:

$$
\phi \geq \rho - \frac{(1-\beta\rho)(1-\rho)}{\kappa}. \tag{71}
$$

From equation (70), μ_{t+1} is greater than μ_{new}. When condition (71) is satisfied at $\phi > 1$, the inflation decreases to the new steady state from date $t = 1$. The initial inflation can be higher or lower than the old steady state value. Also, the output gap declines over time, and converges to the new steady state. Suppose that condition (71) is not satisfied at $\phi = 0$. Then both inflation and output gap initially drop at date $t = 1$, and increases to the associated new steady state levels. So, the monetary policy affects the short-run implications of the model too.