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Abstract

This paper provides a framework to study the macroeconomic implications of supply constraints. Supply constraints hamper firms' ability to scale up production in response to surges in demand, disconnect prices from wages, and create non-linearities and instability in the aggregate Phillips curve. I use the model to show that binding supply constraints amplify the rise in inflation caused by a fiscal stimulus. This happens when the stimulus is large but transitory, when supply disruptions create shortages of intermediate inputs, and when public expenditure targets a few sectors of the economy. A persistent fiscal stimulus, instead, may boost firms' investment and productivity growth in the medium run, while having only a transitory impact on inflation.

JEL Codes: E22, E31, E62, O31, O42

Keywords: Supply constraints, Fiscal stimulus, Inflation, Fiscal multiplier, Multi-sector economy, Convex supply curves, Non-linear Phillips curve, Investment, Productivity

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1 Introduction

The post-pandemic experience is challenging our understanding of the macroeconomy, and in particular of inflation dynamics. Indeed, the recent outburst of inflation has been characterized by a disconnect between prices and wages (Bernanke and Blanchard, 2024b,a). This observation contrasts with the New-Keynesian model - the workhorse framework in monetary economics - which puts emphasis on wages as a prime driver of price inflation (Galí, 2009).[1]

Reconsidering how we model the supply side of the economy, and especially how technological constraints affect firms' price setting, is a promising avenue for progress. This idea is motivated by two empirical facts. First, recent evidence suggests that supply constraints shape firms' pricing behavior. As shown by Boehm and Pandalai-Nayar (2022), in fact, positive demand shocks barely affect prices in sectors operating at normal levels of capacity utilization, while they cause sharp price increases in sectors close to full capacity. Moreover, prices become particularly sensitive to demand shocks when firms' access to some key production inputs is curtailed (Balleer and Noeller, 2023). Second, supply constraints are endogenous to the macroeconomic environment. In particular, large increases in demand lead firms to overcome their supply constraints by adopting more efficient production techniques (Ilzetzki, 2024). In spite of their empirical relevance, these forces are overlooked in mainstream versions of the New-Keynesian model.

This paper, building on these two empirical facts, provides a framework to explore the implications of supply constraints for price setting and inflation. The model is simple enough so that it can be solved analytically, and studied using a graphical approach. I use the framework to revisit a classic question in macroeconomics, that is the impact of fiscal stimulus on inflation. This choice is dictated by the debate surrounding the inflationary consequences of two large fiscal packages, the Consolidated Appropriations Act (December 2020) and the American Rescue Plan Act (March 2021), implemented in the United States during the pandemic (Blanchard, 2021; Krugman, 2023).[2]

The key feature of the model is that firms face occasionally binding supply constraints. These constraints capture technological factors that hamper firms' ability to scale up output swiftly, perhaps because of limited availability of specialized inputs that are complementary to labor in production. Hence, supply constraints bind when firms face unusually high demand for their products. But they can also bind due to shortages of some key production inputs. In any case, once supply constraints start binding, increasing production comes at the cost of efficiency losses and lower labor productivity. As a result, binding supply constraints act in a similar way as endogenous markup shocks driving prices above wages.

Consistent with the empirical evidence provided by Boehm and Pandalai-Nayar (2022), firms' supply curves are convex. When supply constraints are slack, marginal costs and prices are rigid.

[1] Inflation expectations are the other major driver of inflation in the New-Keynesian framework. However, at least at first sight, inflation expectations do not explain much of the post-pandemic inflation cycle (Bernanke and Blanchard, 2024b,a). Moreover, there are theoretical reasons to think that the New Keynesian model overstates the impact of inflation expectations on firms' pricing behavior (Werning, 2022).

[2] To be clear, the main objective of these programs was to provide insurance against the pandemic shock, rather than stimulus per se (Romer, 2021). Nonetheless, understanding their impact on inflation is an interesting research question.

Once output exceeds the threshold that makes supply constraints bind, marginal costs and prices become increasing in the quantity produced. Hence, supply curves are initially flat, and become upward-sloped after the threshold output is reached. Moreover, shocks creating shortages of intermediate inputs shift around the upward-sloped portion of the supply curves, in line with the empirical findings of Balleer and Noeller (2023).

The Phillips curve - defined as the aggregate inflation-output trade-off - inherits the non-linearities of the sectoral supply curves. So the Phillips curve is initially flat, and becomes upward-sloped after GDP is high enough to make supply constraints bind. Moreover, the Phillips curve implied by the model is far from stable. In fact, macroeconomic shocks and policy interventions move it around, creating complex inflation dynamics.

I illustrate the workings of the framework by studying the inflation response to changes in government consumption. Throughout, I assume that monetary policy holds the real interest rate constant, so that private consumption does not react to fiscal shocks. I make this choice because it is well understood that monetary policy determines the private expenditure response to changes in government purchases, and so the fiscal multiplier (Woodford, 2011). I am instead interested in deriving the *fiscal Phillips multiplier*, that is the change in inflation caused by a fiscal stimulus raising GDP by one percent (Barnichon and Mesters, 2021).[3]

At a broad level, the fiscal Phillips multiplier is high when supply constraints bind. In this case, in fact, firms' efforts to accommodate higher government expenditure by ramping up their output generate productivity losses. The outcome is akin to a markup shock increasing prices above wages, because wages do not fully reflect marginal production costs when firms are constrained by technological factors. This effect may explain why the recent US fiscal stimulus coincided with a sharp rise in price inflation, without a comparable acceleration of wage inflation (Bernanke and Blanchard, 2024b).

The model implies that a fiscal stimulus is particularly likely to be inflationary if it is large, and if it coincides with negative supply shocks creating shortages of production inputs. These, in fact, are exactly the conditions under which supply constraints are more likely to bind, pushing the economy on the steep portion of the Phillips curve. Interestingly, the recent US fiscal stimulus programs were both unusually large, and coincided with the extraordinary disruptions induced by the pandemic. The model thus suggests that these fiscal packages were associated with high fiscal Phillips multipliers, and compounded the inflationary pressures caused by pandemic-related supply disruptions.

Moreover, the pandemic fiscal packages were implemented against the background of very high households' expenditure on manufactured goods relative to services. Indeed, beside the fact that contagion risk discouraged consumption of contact-intensive services, fiscal policy may have contributed to this unusual expenditure pattern by fostering households' expenditure on durable goods. More broadly, it is often the case that government expenditure concentrates on some specific

[3] To be precise, Barnichon and Mesters (2021) define the Phillips multiplier in terms of the inflation-unemployment trade-off. Here, it is more convenient to state it in terms of the inflation-output trade-off.

sectors (Cox et al., 2024), the most obvious example being military spending. To investigate the implications of these facts, I then turn to a multi-sector economy.

First, I show that an increase in government spending concentrated on a few sectors of the economy is associated with a high fiscal Phillips multiplier. The reason is simple. Cramming public demand on a few sectors pushes the targeted firms against their supply constraints, forcing them to increase prices. Due to this effect, an unbalanced fiscal expansion induces an adverse shift of the Phillips curve, i.e. a worsening of the aggregate inflation-output trade-off.

Second, the impact of a fiscal stimulus on inflation is magnified during times of unbalanced demand, that is when the private sector reallocates its expenditure across different sectors. This happens because supply constraints hamper the economy's ability to adjust to the new demand mix. In fact, as in Guerrieri et al. (2021) and Fornaro and Romei (2023), demand reallocation shocks look like cost-push shocks, leading to an adverse shift of the aggregate Phillips curve. A fiscal stimulus then amplifies the inflationary pressures due to the reallocation shock, by boosting inflation in those sectors experiencing unusually high demand.

In the last part of the paper, I allow firms to relax their supply constraints by investing. Consistent with the empirical evidence provided by Ilzetzki (2024), a large fiscal stimulus induces firms to invest in technology upgrading. This effect creates an intertemporal inflation trade-off. On the one hand, investment amplifies the inflationary pressures caused by the fiscal stimulus in the short run. On the other hand, higher productivity reduces firms' marginal costs and inflation in the medium run. When this effect is strong enough, a fiscal stimulus has a transitory impact on inflation, while its positive effect on productivity is long-lasting.

The paper is connected to a recent literature studying the implications of supply constraints for inflation. Prominent examples are Boehm and Pandalai-Nayar (2022), Bai et al. (2024), Comin et al. (2023) and Di Giovanni et al. (2023). These works provide rich medium-scale models, and perform quantitative analyses. This paper takes a complementary approach, by offering a simple model useful to build up intuition. Fornaro and Romei (2023), Fornaro et al. (2024) and Lorenzoni and Werning (2023) take a similar approach to explore the implications of supply constraints respectively for international inflation spillovers, the energy transition and conflict inflation. This paper, instead, focuses on the inflationary consequences of fiscal stimulus.

The paper is also related to the literature studying inflation dynamics when downward wage rigidities give rise to a non-linear Phillips curve (Akerlof et al., 1996; Benigno and Ricci, 2011; Schmitt-Grohé and Uribe, 2016; Benigno and Eggertsson, 2023; Gitti, 2024). Barnichon et al. (2022), Born et al. (2024) and Fornaro and Grosse-Steffen (2024) study the inflationary consequences of fiscal stimulus when wages are downwardly rigid. Different from these works, in this paper the Phillips curve is non-linear because of supply constraints, so the model is consistent with the disconnect between prices and wages observed during the pandemic-era inflation cycle.

Recently, there has been a surge of works studying inflation in multi-sector economies (Ghassibe, 2021; Guerrieri et al., 2021; Rubbo, 2023). In particular, Bouakez et al. (2018) and Cox et al. (2024) study the inflationary consequences of fiscal stimulus in multi-sector economies. They emphasize the role of structural sectoral differences in price stickiness. In this paper, instead, price stickiness is endogenous and shaped by supply constraints.

Finally, this paper builds on a recent literature studying monetary and fiscal policy when potential output is endogenous due to firms' investment in new technologies. Some examples of this literature are Benigno and Fornaro (2018), Fatás and Summers (2018), Anzoategui et al. (2019), Garga and Singh (2021), Fornaro and Wolf (2022, 2023, 2024) and Queralto (2022). A distinctive feature of this paper is the focus on supply constraints and firms' efforts to relax them.

The rest of the paper is composed by five sections. Section 2 presents the baseline model. Section 3 provides some preliminary results on the inflationary consequences of fiscal stimulus. Section 4 extends the model to a multi-sector economy. Section 5 introduces investment and technology upgrading. Section 6 concludes.

2 Baseline model

Consider an infinite-horizon closed economy. Time is discrete and indexed by $t \in \{0, 1, 2, ...\}$. The economy is inhabited by households, firms, and by a government that sets fiscal and monetary policy. For simplicity, I will assume perfect foresight.

2.1 Households

There is a continuum of measure one of identical households deriving utility from consumption of a homogeneous "final" good. The lifetime utility of the representative household is

$$\sum_{t=0}^{\infty} \beta^t \log C_t, \tag{1}$$

where $0 < \beta < 1$ is the subjective discount factor and C_t denotes consumption. The households' budget constraint is

$$P_t C_t + B_{t+1} = W_t L_t + D_t - T_t + (1 + i_{t-1}) B_t, \tag{2}$$

where P_t denotes the nominal price of the final good, B_t one-period nominal bonds held by the households, W_t and L_t the nominal wage and employment respectively, D_t the firms' dividends that are distributed to the households, T_t lump-sum taxes levied by the government, and i_t the nominal interest rate. At each time t, households allocate their total income between consumption expenditure and bonds purchases. Optimal saving behavior implies

$$C_t = \frac{C_{t+1}}{\beta} \frac{P_{t+1}}{(1 + i_t) P_t} = \frac{C_{t+1}}{\beta(1 + r_t)}, \tag{3}$$

where r_t denotes the real interest rate. The consumption path also satisfies a standard transversality condition.

Households would like to work $\bar{L}$ units of labor every period. Due to wage rigidities, however, employment L_t is determined by firms' labor demand and may deviate from $\bar{L}$. Throughout the paper, I will focus on a simple case in which nominal wages are fully rigid and $W_t = W$ for all t. This assumption, while not realistic, is useful because it highlights how this model differs from theories in which price inflation is mainly determined by wages.

2.2 Firms and production

Empirical evidence suggests that sectoral supply curves are convex (Boehm and Pandalai-Nayar, 2022). This means that the elasticity of prices with respect to output increases sharply as firms approach their maximum production capacity. This behavior can be rationalized with the presence of technological supply constraints, limiting firms' ability to scale up production swiftly. The firms' side of the model is designed to capture these notions in a tractable way.

The final good is produced by a continuum of mass one of identical competitive firms. Each firm needs to perform two tasks, say A and B, to produce. Let $L_{A,t}$ and $L_{B,t}$ be the amount of labor allocated respectively to tasks A and B by the representative firm. Final output Y_t is

$$Y_t = \left(\frac{L_{A,t}}{\alpha}\right)^{\alpha} \left(\frac{L_{B,t}}{1-\alpha}\right)^{1-\alpha}, \tag{4}$$

where the parameter $0 < \alpha < 1$ determines the importance of the two tasks in the production process. Since labor is homogeneous, every worker is payed the same wage regardless of the task that she fulfills.

Firms face a technological constraint, which limits the amount of labor that can be allocated to task B

$$L_{B,t} \leq (1-\alpha)\bar{Y}_t, \tag{5}$$

where the variable $\bar{Y}_t$ determines the severity of this constraint on supply. This supply constraint could arise from limited availability of a specialized input, perhaps organizational or physical capital, that is complementary to labor in performing task B. For now, we will take $\bar{Y}_t$ as an exogenous variable.

Denote by $L_t = L_{A,t} + L_{B,t}$ the total amount of labor employed in production. Now suppose that the supply constraint does not bind. The optimal allocation of labor by firms between the two tasks implies $L_{A,t} = \alpha L_t$, $L_{B,t} = (1-\alpha)L_t$ and $Y_t = L_t$. One can then see that the supply constraint does not bind if $Y_t \leq \bar{Y}_t$. If this condition is violated, instead, $L_{B,t} = (1-\alpha)\bar{Y}_t$ and

$$Y_t = \left(\frac{L_{A,t}}{\alpha}\right)^{\alpha} \left(\bar{Y}_t\right)^{1-\alpha} = \left(\frac{L_t - (1-\alpha)\bar{Y}_t}{\alpha}\right)^{\alpha} \left(\bar{Y}_t\right)^{1-\alpha}, \tag{6}$$

where the second equality makes use of the fact that when the supply constraint binds $L_{A,t} = L_t - (1-\alpha)\bar{Y}_t$.

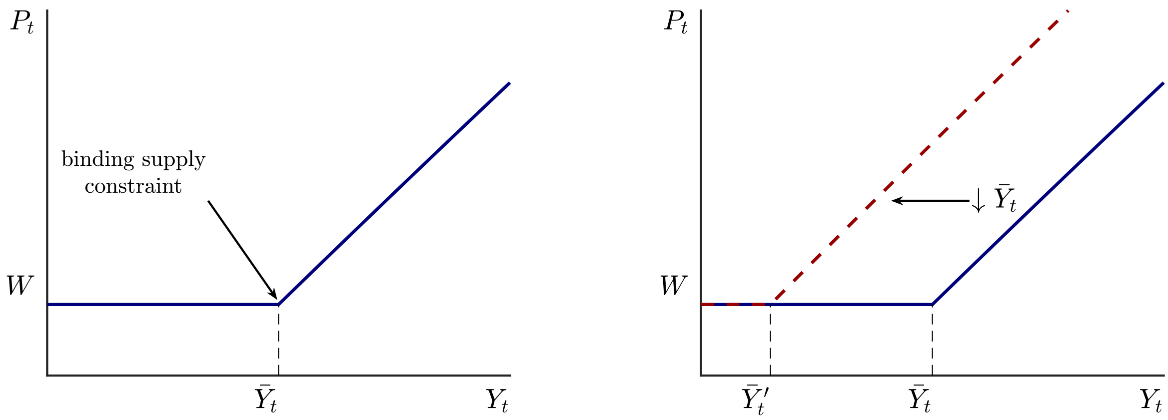

Figure 1: Convex supply curves.

The relationship between output and employment is thus given by

$$Y_t = \begin{cases} L_t & \text{if } Y_t \leq \bar{Y}_t \\ \left(\frac{L_t - (1-\alpha)\bar{Y}_t}{\alpha \bar{Y}_t}\right)^{\alpha} \bar{Y}_t & \text{if } Y_t > \bar{Y}_t. \end{cases} \tag{7}$$

Hence, output is linear in labor up to the threshold $\bar{Y}_t$. Once output exceeds $\bar{Y}_t$, supply constraints start binding and labor productivity declines in the quantity produced. The implication is that the supply curve, defined as the relationship between output and prices, takes the form

$$P_t = \begin{cases} W & \text{if } Y_t \leq \bar{Y}_t \\ W \left(\frac{Y_t}{\bar{Y}_t}\right)^{\frac{1-\alpha}{\alpha}} & \text{if } Y_t > \bar{Y}_t. \end{cases} \tag{8}$$

Intuitively, due to perfect competition the price of the final good is equal to the marginal production cost. When supply constraints do not bind, marginal costs are constant and prices fully inherit the nominal wage rigidity. When supply constraints bind, marginal costs - and so prices - become increasing in the quantity produced. Hence, the supply curve has a flat part corresponding to levels of output below $\bar{Y}_t$, and becomes upward-sloped thereafter (Figure 1). Supply curves are therefore convex, as documented empirically by Boehm and Pandalai-Nayar (2022).

The assumption of a time-varying supply constraint $\bar{Y}_t$ captures the idea that firms' supply curves can shift around due to shocks creating shortages of some key production inputs.[4] As an

[4]More formally, suppose that to perform task B each unit of labor has to be combined with one unit of input X. Every period, the economy receives an endowment of X equal to $(1-\alpha)\bar{Y}_t$, which is supplied competitively by its owners on the market. It is easy to see that the aggregate production function of this economy is given by (7). Moreover, if $Y_t \leq \bar{Y}_t$ then excess supply drives the price of X to zero, while if $Y_t > \bar{Y}_t$ the price of X is equal to its marginal product. The price of the final good is then pinned down by (8), and shocks to the endowment of X shift around firms' supply curves.

This example makes clear that a binding supply constraint can be interpreted as a shortage of production inputs. Throughout the paper, I assume that the input in short supply is owned by the firms. However, not much would change if it was owned by other agents in the economy. For instance, X could be interpreted as some form of specialized labor supplied by the households.

example, the right panel of Figure 1 shows that a drop in $\bar{Y}_t$ causes a leftward shift of the kink of the supply curve. This feature of the model is consistent with the empirical evidence provided by Balleer and Noeller (2023). Using German firm-level data, they show that firms facing shortages of intermediate inputs are particularly likely to increase prices in response to positive demand shocks.

2.3 Fiscal and monetary policy

The fiscal authority sets a path for government consumption G_t. Government expenditure is fully financed through lump-sum taxes, so $P_t G_t = T_t$. To ensure the existence of a steady state, I assume that government consumption converges in the long run to a constant value G, where the absence of a time subscript denotes the steady state value of a variable.

For the purposes of this paper, G_t encapsulates a variety of fiscal interventions that have a direct impact on consumption. So G_t can be interpreted literally as government consumption. With a bit of imagination, one could also interpret G_t as public transfers to hand-to-mouth consumers. For instance, insofar as they stimulated consumption expenditure by borrowing-constrained households, the large transfer programs implemented by the US government during the recovery from the Covid-19 pandemic can be captured by a rise in G_t.

The monetary authority sets the nominal interest rate i_t. I will assume that the central bank maintains the real interest rate constant, and equal to its steady state value ($1 + r_t = 1/\beta$). This policy implies that private consumption is also constant and equal to its value in steady state, i.e. $C_t = C$. I make this choice because it is well understood that monetary policy, through its impact on private expenditure, determines how output reacts to fiscal shocks (Woodford, 2011). In this paper I focus on a different issue, that is how fiscal stimulus affects the relationship between output and inflation. This simple form of monetary policy allows me to do so.

2.4 Market clearing and definition of equilibrium

Final output is consumed either by households or the government, and so

$$Y_t = C + G_t. \tag{9}$$

Equilibrium employment is then determined by firms' labor demand, according to expression (7).

I assume that in the final steady state supply constraints do not bind and employment is equal to households' desired labor supply (i.e. $\bar{Y} > \bar{L} = L$). Private consumption is then determined by

$$C = \bar{L} - G. \tag{10}$$

A competitive equilibrium is then defined as a path of output Y_t and prices P_t satisfying (8) and (9), given a path for the supply constraint $\bar{Y}_t$, and a path for government consumption G_t.

3 A first look at the inflation response to fiscal stimulus

We are now ready to study the macroeconomic impact of fiscal stimulus. Tracing the impact of public expenditure on output is straightforward. Given that monetary policy keeps private consumption constant, equation (9) implies that $\partial Y_t/\partial G_t = 1$. Hence, output moves one-for-one with government consumption.[5]

Let us now turn to inflation. The firm-level supply curves that we just derived can be aggregated to obtain a Phillips curve, that is a relationship between aggregate output and prices. This is shown in Figure 2. In this simple baseline model, fiscal stimulus just moves the economy along the Phillips curve.

The first, rather straightforward, result is that the inflation response to fiscal stimulus is state dependent.[6] In fact, the (local) fiscal Phillips multiplier - that is the change in inflation caused by a fiscal stimulus marginally raising GDP - is given by[7]

$$\frac{\partial P_t}{\partial Y_t}\frac{Y_t}{P_t} = \begin{cases} 0 & \text{if } G_t + C = Y_t < \bar{Y}_t \\ \frac{1-\alpha}{\alpha} & \text{if } G_t + C = Y_t > \bar{Y}_t. \end{cases} \tag{11}$$

If $G_t < \bar{Y}_t - C$, output lies below the threshold $\bar{Y}_t$, the economy is on the flat part of the Phillips curve, and inflation does not react to marginal changes in G_t. If government expenditure exceeds the threshold $\bar{Y}_t - C$, supply constraints bind and the economy is on the upward-sloped portion of the Phillips curve. Intuitively, supply constraints reduce firms' ability to scale up production in response to higher demand, so firms partly adjust to the fiscal stimulus by revising prices upward. The technological nature of this effect explains why its strength is decreasing in α. A lower α, in fact, means that supply constraints are more salient for the production process.

Given the importance of the parameter α for the model, what do we know about its empirical relevance? Boehm and Pandalai-Nayar (2022), using US manufacturing data, estimate the elasticity of sectoral prices with respect to output for different levels of capacity utilization.[8] They find that for values of capacity utilization below the 15th percentile, i.e. when supply constraints are slack, the elasticity is essentially zero. At the other end of the spectrum, for values of capacity utilization above the 85th percentile they find an elasticity of 0.57. The model counterpart of this statistic would be a value of $\alpha = 0.64$. This evidence suggests that supply constraints are a quantitatively important determinant of firms' pricing behavior, and so potentially of the fiscal Phillips multiplier.

A second insight is that the size of the fiscal stimulus matters. To see how, focus on the left panel of Figure 2 and imagine that the economy starts from point a. A modest rise in government

[5] Of course, this result derives from the assumption that monetary policy holds the real interest rate constant. As discussed extensively by Woodford (2011), a contractionary monetary response to the fiscal stimulus would reduce its impact on output.

[6] Boehm and Pandalai-Nayar (2022) provide a detailed analysis of this effect.

[7] The local fiscal Phillips multiplier is not well defined around the point $Y_t = \bar{Y}_t$, i.e. around the kink of the supply curve.

[8] See Table 3 in their paper.

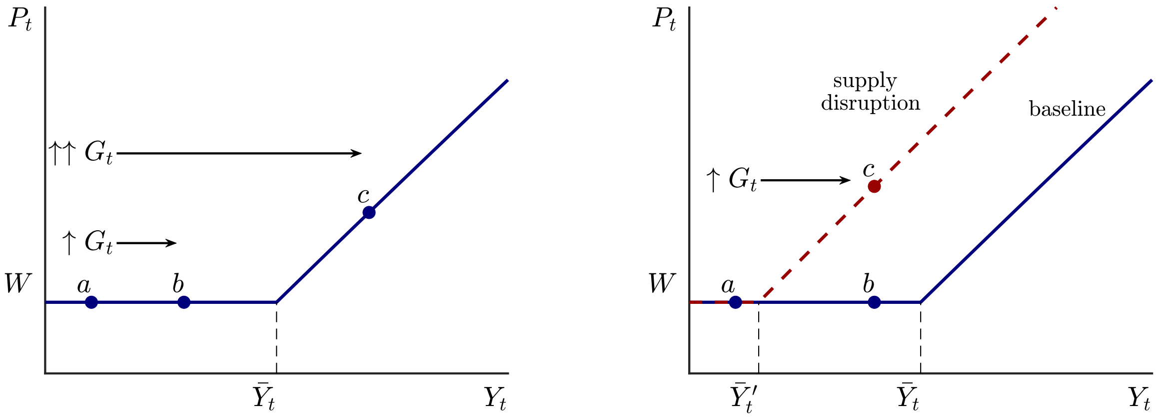

Figure 2: Inflation response to fiscal stimulus.

expenditure, moving the economy to point b, does not affect inflation. But now consider a large fiscal stimulus, moving the economy to point c. In this case, supply constraints start binding, firms' marginal costs rise and inflation emerges. The message is that, while firms may easily adjust to small changes in demand, technological constraints become salient when a large fiscal stimulus triggers a sizable increase in demand.[9]

A third, perhaps less obvious, result is that the fiscal Phillips multiplier is particularly high when supply disruptions create shortages of production inputs. Imagine that a supply disruption causes a drop in $\bar{Y}_t$, i.e. a tightening of the supply constraints faced by firms. The result is a leftward shift of the upward-sloped portion of the Phillips curve, and so a fall in the amount of fiscal stimulus that can be administered without causing supply constraints to bind. This is illustrated by the right panel of Figure 2, which compares a normal economy (solid blue line), to one facing a supply disruption (dashed red line). Now consider a fiscal stimulus that would not affect inflation under normal conditions, moving the economy from point a to b. The same fiscal stimulus moves the economy to point c if implemented in the context of supply disruptions, giving rise to a burst of inflation. Therefore, supply disruptions compound the inflationary pressures caused by higher government consumption.

Before moving on, two remarks are in order. The first one is that there is a key difference with respect to the transmission channel at the heart of the baseline New Keynesian model (Galí, 2009). In the New Keynesian framework, a fiscal stimulus leads to higher inflation by increasing labor market tightness and nominal wage growth.[10] Here, instead, prices rise in spite of the fact that wages do not react to the fiscal stimulus. The reason is that wages do not fully reflect firms' marginal production costs when supply constraints bind, so that binding supply constraints

[9] A related implication is that the impact of a fiscal stimulus may be sign dependent. That is, a large fiscal contraction may not have a sizable impact on inflation, if it pushes the economy on the flat part of the Phillips curve. Barnichon et al. (2022) and Born et al. (2024) provide evidence in favor of this effect.

[10] This is also the case in models in which the Phillips curve is non-linear because of downward wage rigidities. Barnichon et al. (2022), Benigno and Eggertsson (2023), Born et al. (2024), Fornaro and Grosse-Steffen (2024) and Fornaro and Romei (2019) are examples of works studying fiscal stimulus in economies with downward wage rigidities.

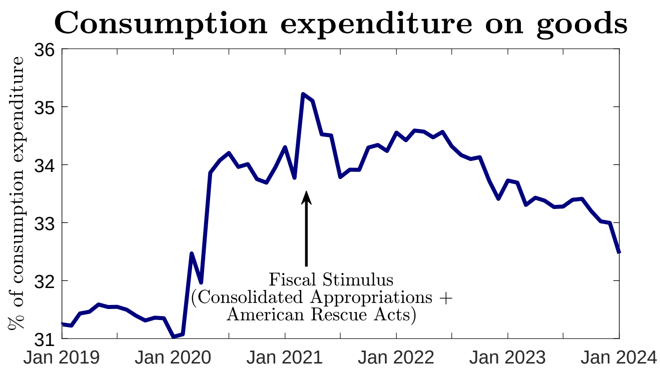

Figure 3: United States: share of personal consumption expenditure on goods.

manifest themselves as endogenous markups of prices over wages.[11]

The second remark is that the model may teach us something about the fiscal stimulus implemented by the US government during the covid recovery. Indeed, just like what the model would predict, the recent US fiscal stimulus coincided with a rise in price inflation, without a comparable acceleration of wage inflation (Bernanke and Blanchard, 2024b). Moreover, the recent fiscal stimulus program was unusually large, and implemented in the context of extraordinary supply disruptions induced by the pandemic. According to the model, both factors should have magnified the fiscal Phillips multipliers associated with these fiscal programs. Hence, empirical estimates of fiscal multipliers derived using data from normal times may underestimate the effect on inflation of these fiscal interventions.

4 Fiscal stimulus in a multi-sector economy

During the recovery from the pandemic, households' expenditure on manufactured goods relative to services rose sharply. Beside the fact that contagion risk discouraged consumption of contact-intensive services, fiscal policy may have contributed to this unusual expenditure pattern. In fact, as shown in Figure 3, the peak in the share of expenditure on manufactured goods coincided with two large fiscal stimulus programs, the Consolidated Appropriations Act (December 2020) and the American Rescue Plan Act (March 2021). More broadly, it is often the case that government expenditure concentrates on some specific sectors (Cox et al., 2024), the most obvious example being military spending. To investigate the implications of these facts, I now move to a multi-sector economy.

[11] As explained in footnote 4, binding supply constraints can be thought of as the result of shortages of inputs complementary to labor in production. In the model, these inputs are internal to the firm, such as physical or organization capital. But considering shortages of inputs external to the firm, such as materials or some form of specialized labor, would not change significantly the analysis. The only difference is that the owners of the production inputs in short supply would earn the rents that accrue to the firms in the model of this paper.

4.1 A multi-sector economy

There are two sectors, manufacturing m and services s. The households' consumption basket aggregates the output of the two sectors according to

$$C_t = \left(\frac{C_t^m}{\omega_t}\right)^{\omega_t} \left(\frac{C_t^s}{1-\omega_t}\right)^{1-\omega_t}, \tag{12}$$

where C_t^j denotes consumption of good j and $0 \leq \omega_t \leq 1$. As is well known, given these preferences households allocate consumption expenditure between the two goods according to

$$P_t^m C_t^m = \omega_t P_t C_t \tag{13}$$

$$P_t^s C_t^s = (1-\omega_t) P_t C_t, \tag{14}$$

where P_t^j is the price of good j and

$$P_t = (P_t^m)^{\omega_t} (P_t^s)^{1-\omega_t}, \tag{15}$$

is the price of a unit of the consumption basket. The exogenous variable ω_t thus captures the private sector's expenditure share on manufacturing, which is potentially time varying.

The production structure is the same as in the baseline model, except that each sector has its own specific supply constraint denoted by $\bar{Y}_t^j$. This means that sectoral prices are given by

$$P_t^j = \begin{cases} W & \text{if } Y_t^j \leq \bar{Y}_t^j \\ W\left(\frac{Y_t^j}{\bar{Y}_t^j}\right)^{\frac{1-\alpha}{\alpha}} & \text{if } Y_t^j > \bar{Y}_t^j, \end{cases} \tag{16}$$

where both sectors face the same nominal wage W, due to the assumption of perfect labor mobility. Hence, as empirically documented by Boehm and Pandalai-Nayar (2022), the supply curves are convex at the sectoral level.

To ease comparison with respect to the baseline model, from now on I will assume that $\bar{Y}_t^m = \omega\bar{Y}$ and $\bar{Y}_t^s = (1-\omega)\bar{Y}$, where ω denotes the private sector's expenditure share on manufacturing in steady state. Intuitively, I am assuming that firms' production capacity is shaped by the long run pattern of consumers' demand.

Fiscal policy is now defined as a path of government consumption of manufactured goods G_t^m and services G_t^s. Market clearing for good j is such that

$$Y_t^j = C_t^j + G_t^j, \tag{17}$$

while real GDP is given by

$$Y_t = C + \frac{P_t^m}{P_t} G_t^m + \frac{P_t^s}{P_t} G_t^s, \tag{18}$$

where $P_t G_t = P_t^m G_t^m + P_t^s G_t^s$ is total government expenditure. I am defining real GDP as nominal

GDP deflated by the consumers' price index. This is a good approximation as long as the CPI does not diverge too much from the GDP deflator.

I maintain the assumption that monetary policy keeps the real rate equal to its steady state value, so that aggregate private consumption C is constant. Finally, labor market clearing implies that $L_t = L_t^m + L_t^s$, where L_t^j denotes total employment in sector j. As in the baseline model, I assume that in steady state the supply constraints do not bind, and so $P^m = P^s = P = W$.

4.2 An unbalanced fiscal stimulus

Let me begin by considering an economy in which households' expenditure shares are constant, that is $\omega_t = \omega$ for all t. To move forward, I need to specify how the government allocates its expenditure between the two goods. Suppose that the government, just like the private sector, allocates a fraction ω of its expenditure to manufacturing, and the complement fraction $1-\omega$ to services. The model then collapses to the baseline one, and all the results derived in Section 3 apply. If the government deviates from this balanced expenditure pattern the analysis becomes more involved, but also more interesting. The reason is that the shape of the Phillips curve depends on the sectoral composition of government consumption.

Consider a case in which fiscal stimulus is targeted toward a single sector. To fix ideas, say that the stimulus is fully targeted toward manufacturing. The government then maintains real expenditure on services constant and equal to its steady state value, i.e. $P_t^s G_t^s / P_t = G^s$, while the intensity of the stimulus is measured by real expenditure on manufacturing $P_t^m G_t^m / P_t$. Under this fiscal policy, real output is equal to

$$Y_t = C + G^s + \frac{P_t^m}{P_t} G_t^m. \tag{19}$$

A unit increase in real government consumption thus causes a unit increase in real GDP.

What about inflation? Start by noticing that sectoral output is equal to

$$Y_t^m = \frac{P_t}{P_t^m} \left(\omega C + \frac{P_t^m}{P_t} G_t^m \right) = \left(\frac{P_t^s}{P_t^m} \right)^{1-\omega} (Y_t - Y^s) \tag{20}$$

$$Y_t^s = \frac{P_t}{P_t^s} \left((1-\omega) C + G^s \right) = \left(\frac{P_t^m}{P_t^s} \right)^{\omega} Y^s, \tag{21}$$

where the second equalities make use of expressions (15) and (19), and of the fact that $Y^s = C^s = (1-\omega)C + G^s$. So government expenditure has a direct impact on the output of the targeted sector, i.e. manufacturing. Moreover, insofar as it affects relative prices and so households' consumption pattern, fiscal stimulus has also an effect on the untargeted service sector.

If the fiscal stimulus is sufficiently small, the supply constraints are slack in both sectors. This is the case if $G_t^m / \omega \leq \bar{Y} - C$, or equivalently if aggregate output lies below the threshold

$$Y_t \leq Y^* = \omega \bar{Y} + Y^s. \tag{22}$$

For these values of real GDP, all the prices are fully rigid and equal to W. Therefore, marginal variations in government purchases have no impact on inflation.

Once output exceeds Y^*, manufacturing firms run against their supply constraints. Further increases in government expenditure then cause P_t^m and inflation to rise. Notice that $Y^* < \bar{Y}$,[12] and so inflationary pressures emerge at lower levels of fiscal stimulus compared to the baseline economy. The reason is simple. Increases in aggregate demand driven by fiscal stimulus now fall exclusively on the targeted sector. Compared to the baseline economy, it then takes a smaller stimulus to push firms (in the targeted sector) on the steep part of their supply curve. Due to this effect, unbalanced fiscal expansions are particularly likely to be inflationary.

As manufacturing goods become more expensive, households reallocate their consumption toward services. Initially, however, firms in the service sector expand production without being hampered by the supply constraints. In this case, the price of services remains equal to $P_t^s = W$, and the consumer price index evolves according to

$$P_t = W \left(\frac{Y_t - Y^s}{\omega \bar{Y}} \right)^{\frac{(1-\alpha)\omega}{1-(1-\alpha)\omega}} . \tag{23}$$

This process goes on until government purchases push output above the threshold

$$Y^{**} = \omega \bar{Y} \left(\frac{(1-\omega)\bar{Y}}{Y^s} \right)^{\frac{1-\omega(1-\alpha)}{\omega(1-\alpha)}} + Y^s. \tag{24}$$

At that point supply constraints start binding in the service sector too. Further fiscal stimulus is then associated with rising prices in both sectors, and the mapping between the price level and output becomes

$$P_t = W \left(\left(\frac{Y_t - Y^s}{\omega \bar{Y}} \right)^{\omega} \left(\frac{Y^s}{(1-\omega)\bar{Y}} \right)^{1-\omega} \right)^{\frac{1-\alpha}{\alpha}} , \tag{25}$$

while the relative price of the two goods behaves according to

$$\frac{P_t^m}{P_t^s} = \left(\frac{Y_t - Y^s}{Y^s} \frac{1-\omega}{\omega} \right)^{1-\alpha} . \tag{26}$$

Hence, inflationary pressures are more intense in the sector targeted by the stimulus.

The left panel of Figure 4 shows graphically how an unbalanced fiscal stimulus affects the Phillips curve. Compared to the baseline economy with a balanced stimulus, targeting government expenditure on a single sector shifts the kink of the Phillips curve toward the left. This means that it takes a smaller stimulus to make supply constraints bind in the targeted sector. Hence, an unbalanced fiscal expansion is particularly likely to be associated with a high fiscal Phillips multiplier.[13]

[12] This result follows from the assumption that supply constraints do not bind in steady state, so that $Y^s < (1-\omega)\bar{Y}$.

[13] Moreover, an unbalanced fiscal stimulus triggers a rise in the relative price of the targeted sector, and of its share in GDP. Because of this effect, the consumer price index - which is based on the private sector's expenditure shares - understates the impact of the fiscal expansion on the GDP deflator. This effect explains why the Phillips curve

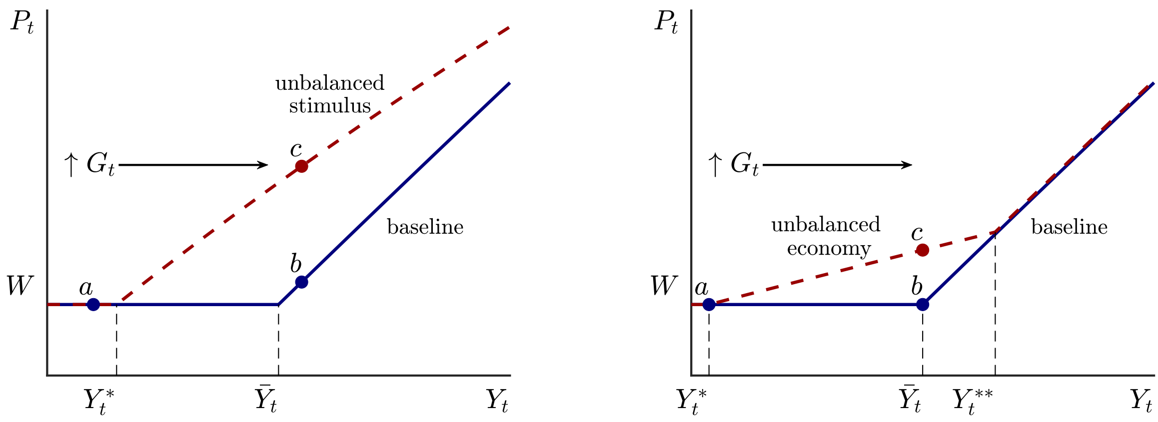

Figure 4: Inflation response to fiscal stimulus in a multi-sector economy.

There is a parallel with the analysis in Cox et al. (2024), who argue that the sectoral composition of government purchases influences their macroeconomic impact. There is also, however, an important difference. Cox et al. (2024) emphasize the role of structural asymmetries in sectoral price stickiness. Here, instead, the presence of supply constraints implies that sectoral price stickiness is an endogenous variable, which is influenced by fiscal policy itself. In particular, in my model a large fiscal stimulus may lead to a sharp increase in price flexibility in the targeted sector. This effect makes it hard to estimate the impact of large fiscal expansions, by extrapolating empirical evidence based on small changes in government purchases.

4.3 Fiscal stimulus in an unbalanced economy

Let us turn to the impact of fiscal stimulus during times of sectoral reallocation, which is exactly the scenario that characterized the recent pandemic. To do so, imagine that the government follows the same expenditure pattern of the private sector

$$G_t = \left(\frac{G_t^m}{\omega_t}\right)^{\omega_t}\left(\frac{G_t^s}{1-\omega_t}\right)^{1-\omega_t}. \tag{27}$$

But now consider a case in which the share of expenditure on manufacturing is unusually high in a given period t, i.e. $\omega_t > \omega$. Sectoral output is then given by

$$Y_t^m = \omega_t \frac{P_t}{P_t^m} Y_t \tag{28}$$

$$Y_t^s = (1-\omega_t)\frac{P_t}{P_t^s} Y_t, \tag{29}$$

where $Y_t = C + G_t$.

displayed in Figure 4, which is based on the CPI, may be flatter when the fiscal stimulus is unbalanced. In fact, if the fiscal stimulus is large enough, this discrepancy becomes so large that the CPI is no longer representative of the total economy.

As in the previous section, if fiscal stimulus is sufficiently small supply constraints are slack in both sectors, and the Phillips curve is flat. This happens when output is below the threshold

$$Y_t^* = \frac{\omega}{\omega_t}\bar{Y}. \tag{30}$$

Once output reaches Y_t^*, further increases in government purchases make the supply constraints bind in the manufacturing sector, causing a rise in inflation. Notice that $Y_t^* < \bar{Y}_t$, so inflationary pressures emerge at a lower level of aggregate demand compared to the baseline economy. Intuitively, there is a mismatch between the sectoral composition of aggregate demand and the productive structure of the economy. This mismatch causes inflation in the sector featuring an unusually high expenditure share, which is not compensated by a drop in prices in the rest of the economy.

As manufacturing goods become more expensive, households reallocate their consumption toward services. Initially, however, the supply constraints in the service sector remain slack and the price level behaves according to

$$P_t = \left(\frac{\omega_t}{\omega}\frac{Y_t}{\bar{Y}}\right)^{\frac{\omega_t(1-\alpha)}{1-\omega_t(1-\alpha)}}. \tag{31}$$

When the fiscal stimulus gets so large that output exceeds the threshold

$$Y_t^{**} = \left(\frac{1-\omega}{1-\omega_t}\right)^{1-\omega_t(1-\alpha)}\left(\frac{\omega}{\omega_t}\right)^{\omega_t(1-\alpha)}\bar{Y}, \tag{32}$$

the supply constraints start binding in the service sector too. Once this happens, further increases in government expenditure foster inflation in both sectors, and the price level is given by

$$P_t = \left(\left(\frac{\omega_t}{\omega}\right)^{\omega_t}\left(\frac{1-\omega_t}{1-\omega}\right)^{1-\omega_t}\frac{Y_t}{\bar{Y}}\right)^{\frac{1-\alpha}{\alpha}}. \tag{33}$$

As illustrated by the right panel of Figure 4, a sectoral reallocation of expenditure acts as a cost-push shock, shifting the Phillips curve upward.[14] The implication is that implementing fiscal stimulus in times of sectoral reallocation is particularly likely to lead to inflationary pressures.[15] Effectively, this happens because supply constraints bind in the sectors facing an unusually high share of demand, hampering the economy's ability to adjust to the new demand mix. This effect explains why reallocation shocks look like negative productivity, or cost-push, shocks from the point of view of the aggregate economy (Guerrieri et al., 2021; Fornaro and Romei, 2023).

[14] To see that this is the case for $Y_t > Y_t^{**}$, just consider that the term

$$\left(\frac{\omega_t}{\omega}\right)^{\omega_t}\left(\frac{1-\omega_t}{1-\omega}\right)^{1-\omega_t}, \tag{34}$$

reaches its minimum at $\omega_t = \omega$.

[15] A clarification is in order. As highlighted by Guerrieri et al. (2022), there are reasons to believe that during a pandemic fiscal multipliers, i.e. the impact of changes in government expenditure on aggregate demand and output, may be lower than usual. Here, instead, I am arguing that during times of sectoral reallocation a fiscal expansion is likely to have a larger than usual impact on inflation, holding constant the fiscal multiplier.

5 Investment and technology upgrading

In an important recent contribution, Ilzetzki (2024) shows that public purchases of military airplanes during WWII pushed US aircraft manufacturers against their supply constraints. Aircraft manufacturers reacted by investing to upgrade their technologies and increase their productive capacity. While this evidence refers to a specific event, the notion that firms will adjust to surges in demand by investing to relax their supply constraints seems quite natural. I now extend the model to explore the macroeconomic implications of this effect.

5.1 Investing in productive capacity

For simplicity, let me go back to the one sector economy described in Section 2. But now firms can invest to relax their supply constraints. In particular, a firm that invests I_t units of the final good in period t increases its future productive capacity according to

$$\bar{Y}_{t+1} = \bar{Y}_t + \chi I_t, \tag{35}$$

where $\chi > 0$ is a parameter determining the productivity of investment. To maximize comparability with the baseline model, I have assumed that productive capacity does not depreciate. So this investment is best thought of as a fundamental technological upgrade, having a persistent impact on future productivity. A good example is the switch from traditional to modern production techniques by US aircraft manufacturers described by Ilzetzki (2024). That said, allowing productive capacity to depreciate would not change the fundamental insights of the model.

To understand firms' incentives to invest, combine expressions (7) and (8) to see that period t profits expressed in units of the final good are equal to

$$Y_t - \frac{W}{P_t} L_t = \max \left[\bar{Y}_t (1-\alpha) \left(\left(\frac{P_t}{W} \right)^{\frac{\alpha}{1-\alpha}} - \frac{W}{P_t} \right), 0 \right]. \tag{36}$$

So firms make zero profits when their supply constraints are slack and $P_t = W$. When supply constraints are binding, however, $P_t > W$ and firms' profits are positive. As it is intuitive, profits are increasing in the price of the final good P_t relative to the cost of labor W. Moreover, profits are proportional to productive capacity $\bar{Y}_t$. This effect implies that the prospect of a binding supply constraint in the future gives an incentive for firms to invest to increase their productivity.

More precisely, firms choose the optimal path of investment by maximizing

$$\sum_{t=0}^{\infty} \left(\frac{1}{1+r} \right)^t \left(Y_t - \frac{W}{P_t} L_t - I_t \right), \tag{37}$$

subject to the law of motion for $\bar{Y}_{t+1}$, and a non-negativity constraint on investment. In words, firms maximize the value of the stream of dividends distributed to the households, which are equal to profits net of investment costs. Dividends are discounted using the households' discount factor.

Absent uncertainty, the discount factor coincides with the real interest rate, which is maintained constant by the central bank. Due to perfect competition, when solving this maximization problem firms take prices as given.

Optimal investment in a generic period t satisfies

$$\frac{1}{\chi} \geq \sum_{\tau=t+1}^{\infty} \left(\frac{1}{1+r}\right)^{\tau-t} \max\left[(1-\alpha)\left(\left(\frac{P_\tau}{W}\right)^{\frac{\alpha}{1-\alpha}} - \frac{W}{P_\tau}\right), 0\right], \tag{38}$$

holding with strict equality if $I_t > 0$. To understand this condition, consider that $1/\chi$ is the cost associated with a marginal increase in $\bar{Y}_{t+1}$. The first term on the right-hand side, instead, is the corresponding marginal increase in profits. Since firms are forward looking, they take into account the impact of a rise in $\bar{Y}_{t+1}$ on the whole stream of future profits. If the marginal cost of investing is higher than the marginal benefit, then firms do not invest. Otherwise, firms invest until the marginal cost is equal to the marginal benefit.[16]

To close the model, we have to modify to market clearing condition to

$$Y_t = C + G_t + I_t, \tag{39}$$

since now final output is split between consumption and investment. To maintain symmetry with the baseline model, I assume that $\bar{Y}_0$ is high enough so that in the final steady state supply constraints do not bind. This implies that in steady state firms do not invest, and so $C = \bar{L} - G$.

A competitive equilibrium is then defined as a path of output Y_t, supply constraints $\bar{Y}_t$, investment I_t and prices P_t satisfying (8), (35), (38) and (39), given an initial supply constraint $\bar{Y}_0$, and a path for government consumption G_t.

5.2 Fiscal stimulus and the intertemporal inflation trade-off

Now consider the following path for government consumption

$$G_t = \begin{cases} G^h > G & \text{if } t \leq T \\ G & \text{if } t > T, \end{cases} \tag{40}$$

where G denotes government expenditure in the initial and final steady states, while G^h can be thought of as a temporary fiscal stimulus lasting for T periods. If the fiscal stimulus is fully transitory, i.e. if $T = 0$, the model collapses to the baseline one studied in Section 2. To make things interesting, suppose that the stimulus is persistent and so $T > 0$.

As in the baseline model, the fiscal stimulus does not affect private consumption which remains equal to C. Tracing the impact of the stimulus on investment is a little harder. Given that supply constraints do not bind once government consumption has reverted to its steady state value, firms

[16]In principle, the marginal cost of investment could be lower than the marginal benefit. In that case, however, firms would set investment to infinity, which cannot be an equilibrium.

have no incentives to invest after period T. Moreover, for the path of government consumption that we are considering, firms' incentives to invest are fully front-loaded.[17] So the investment response to the stimulus is determined by firms' behavior in period $t = 0$.

It turns out that there are two possibilities. First, investment may be unprofitable. Firms' productive capacity will then remain constant and equal to its initial value ($\bar{Y}_t = \bar{Y}_0$), while output will follow the path $Y_t = C + G_t$. Using (8) and (38) gives that this no-investment equilibrium materializes if

$$\frac{1}{\chi} > \sum_{\tau=1}^{T} \left(\frac{1}{1+r}\right)^{\tau} \max\left[(1-\alpha)\left(\left(\frac{G^h + C}{\bar{Y}_0}\right) - \left(\frac{\bar{Y}_0}{G^h + C}\right)^{\frac{1-\alpha}{\alpha}}\right), 0\right], \tag{41}$$

so if the fiscal stimulus G^h is sufficiently small. In this case, inflation will behave exactly as described in the baseline model.

The second scenario - arguably the most interesting one - occurs when the fiscal stimulus is large and condition (43) is violated. In this case, the stimulus puts so much pressure on supply constraints that it becomes profitable for firms to invest to increase their future productive capacity. The result is a burst of investment in period 0,[18]

$$I_t = \begin{cases} \frac{\bar{Y}^h - \bar{Y}_0}{\chi} & \text{if } t = 0 \\ 0 & \text{if } t > 0, \end{cases} \tag{42}$$

which pushes productive capacity to a higher level $\bar{Y}^h > \bar{Y}_0$. The new level of productive capacity $\bar{Y}^h$ solves

$$\frac{1}{\chi} = \sum_{\tau=1}^{T} \left(\frac{1}{1+r}\right)^{\tau} (1-\alpha)\left(\left(\frac{G^h + C}{\bar{Y}^h}\right) - \left(\frac{\bar{Y}^h}{G^h + C}\right)^{\frac{1-\alpha}{\alpha}}\right). \tag{43}$$

A persistent fiscal stimulus thus crowds in investment in the short run, i.e. in period $t = 0$, which translates into higher productivity in the medium run, i.e. in periods $0 < t \leq T$.

Moreover, the fact that firms respond to the stimulus by upgrading their technology creates an intertemporal inflation trade-off. The path of the price level is given by

$$P_t = \begin{cases} W\left(\frac{C+G^h+I_0}{\bar{Y}_0}\right)^{\frac{1-\alpha}{\alpha}} > W & \text{if } t = 0 \\ W\left(\frac{C+G^h}{\bar{Y}^h}\right)^{\frac{1-\alpha}{\alpha}} < P_0 & \text{if } 0 < t \leq T \\ W & \text{if } t > T. \end{cases} \tag{44}$$

So, as in the baseline model, the stimulus makes supply constraints bind creating a burst of

[17] Formally, when G_t follows the process (40), the right-hand side of expression (38) reaches its maximum in period $t = 0$.

[18] The fact that investment is fully front-loaded is specific to the assumption of linear investment function. Adding decreasing returns to scale in the investment technology, or other forms of investment adjustment costs, would induce firms to smooth investment over time. Still, under reasonable assumptions, firms will invest more at the start of the stimulus, that is when the marginal benefit from investing is highest.

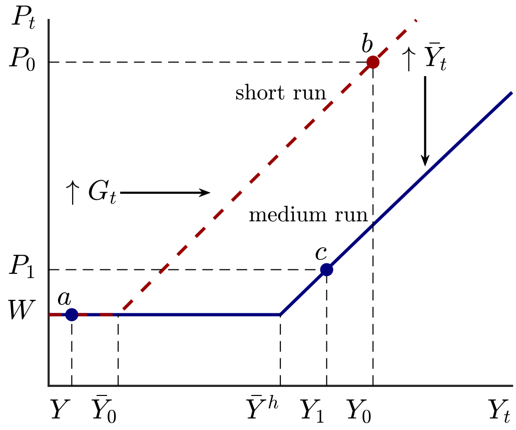

Figure 5: Inflation response to fiscal stimulus with endogenous technology.

inflation. In the short run, investment amplifies this rise in inflation, because it contributes to boost aggregate demand for firms' products. In the medium run, however, higher productivity reduces firms' marginal costs, thus allowing them to decrease prices. Hence, compared to an economy with exogenous technology, the price level is higher in the short run, but lower in the medium run.

Figure 5 illustrates this intertemporal inflation trade off. In the short run, the fiscal stimulus moves the economy along the Phillips curve from point a to b, leading to a rise in the price level. In the medium run, however, firms' adoption of more productive technologies makes the Phillips curve shift toward the right. As the economy jumps on the new Phillips curve, moving from point b to c, the price level drops.

Taking stock, a persistent fiscal stimulus may lead to a transitory rise in inflation, if accompanied by a surge of business investment. Moreover, a fiscal stimulus may end up having a persistent positive impact on productivity. Understanding the empirical strength of these effects is a first order issue, both for academics and policymakers.

Direct evidence on the impact of government purchases on productivity, along the lines of Ilzetzki (2024), is still scarce. But two recent empirical studies point toward a positive link between fiscal expansions and productivity. First, Cloyne et al. (2024, 2023) show that lower taxes on business investment trigger future increases in productivity, accompanied by declines in future inflation. This is precisely what our simple theory of supply constraints predicts. Second, Antolin-Diaz and Surico (2024) document that increases in public R&D spending cause higher future productivity. Interestingly, they find that public R&D crowds in private investment, both in physical capital and R&D. While more evidence is needed, these studies suggest that firms' ability to adapt their technologies to the macroeconomic environment should be taken into account when evaluating fiscal stimulus programs.

6 Conclusion

As we have seen, supply constraints are likely to be important to explain firms' price setting and the inflation response to fiscal stimulus. But supply constraints may be relevant to understand other aspects of our economies. Let me make this point by drawing on my own research. In Fornaro and Romei (2023, 2024), we connect sectoral supply constraints to international inflation spillovers, and argue that the pandemic fiscal packages implemented by the US might have exported inflation toward the rest of the world, by pushing global manufacturing firms against their supply constraints. In Fornaro et al. (2024), instead, we suggest that constraints on the use of dirty sources of energy may create inflationary pressures during the transition to a green economy. These are just some examples, and much more theoretical and empirical work is needed to explore the macroeconomic implications of supply constraints.

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