Taxation, Aggregate Price Stickiness, and Economic Fluctuations*

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Abstract

We study the impact of taxation on aggregate price stickiness in New Keynesian economics. We show that taxation increases aggregate price stickiness. Moreover, we show that the magnitude of the impact of taxation on aggregate price stickiness is "first-order" large. Our results suggest that taxes act as automatic destabilizers on the supply side, which is in sharp contrast with the traditional role of automatic stabilizers played by taxes on the demand side. Hence, the net impact of taxes on economic fluctuations is theoretically ambiguous.

Key words: Automatic Stabilizers; New Keynesian Economics; Price Stickiness; Taxation

JEL classification: E; H

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I. INTRODUCTION

Although price stickiness is central to Keynesian models, in most such models it has no solid microeconomic foundation. Thus, construction of microeconomic foundations for price stickiness is a top priority for New Keynesian economists.

To meet the above challenge, New Keynesian economists have put forward two parallel ideas, namely, small menu costs (Mankiw, 1985) and near-rationality (Akerlof and Yellen, 1985).[1] By menu costs, Mankiw (1985) refers to the costs for changing prices that might include such items as "printing new catalogs, informing salesmen of the new price, and any other costs associated with price adjustment."[2] In the small menu costs model, a firm will keep its price unchanged following a money supply shock[3] if the profit increment from price adjustment is less than its menu costs. By near-rationality, Akerlof and Yellen (1985) mean "nonmaximizing behavior in which the gains from maximizing rather than nonmaximizing are small in a well-defined sense." In the near-rationality model, the monopolistically competitive economy suggests that following a money supply shock, the profit loss for an individual firm to keep its price unchanged, rather than changing its price to charge the new optimal price, is merely in second-order of the money supply shock. Thus, if a firm keeps its price unchanged following a money supply shock, its behavior is suboptimal, but still near-rational because its profit loss is merely in second-order of the money supply shock.

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[1]The following studies in this literature (for example, Blanchard and Kiyotaki, 1987; Ball and Romer, 1989, 1990, and 1991), in general, expand on the near-rationality model by Akerlof and Yellen (1985). The key difference is that they derive their results from basic optimization assumptions so that explicit welfare calculations are allowed. See, for example, Rotemberg (1987) and Blanchard (1990) for comprehensive surveys of this literature.
[2]Those costs are called menu costs because they can be vividly viewed as the price of printing a new menu.
[3]For notational convenience, we use m and ε to denote the money supply and the money supply shock, respectively. The money supply shock is defined as the fractional change in the money supply. That is, the money supply would change from m to $m(1+\varepsilon)$ with a money supply shock ε.

The papers in the aforementioned literature share three common features. First, they assume that all the firms are homogeneous or identical. Second, they show that a second-order "small" price-adjustment barrier[4] for an individual firm to adjust its price can cause changes in money supply to have a first-order "large" effect on real economic variables, either on social welfare (Mankiw, 1985) or on employment (Akerlof and Yellen, 1985). Finally, the fraction of the firms that keep their price unchanged following a money supply shock is exogenous.[5] In the initial equilibrium of their models, each firm is assumed to set its own price to maximize its own profit. Then, they introduce a money supply shock into their models. Following the money supply shock, they assume that β fraction of the firms keep their price unchanged, whereas the remaining $(1-\beta)$ fraction of the firms change their price to charge the new optimal price. They either assume a general β that is between zero and one (Akerlof and Yellen, 1985), or assume that β is equal to a specific value, namely, one (for example, Mankiw, 1985; Blanchard and Kiyotaki, 1987; Ball and Romer, 1989, 1990, and 1991). But no matter what, β is exogenous in their models.

It is fine for their research purposes to assume that β is exogenous. However, β should be an endogenous variable. More importantly, it can, by definition, be considered as a measure of aggregate price stickiness. Provided that one can endogenize β, he can go one step further to characterize the behavior of aggregate price stickiness by studying the properties of the endogenized β.

[4]Small menu costs and near-rationality are, by definition, obviously equivalent routes to the same place. For the convenience of exposition, we thus follow An (2009) to give them a unified terminology, namely, price-adjustment barrier.

[5]For notational convenience, we use β to denote the fraction of the firms that keep their price unchanged following a money supply shock.

An (2009) characterizes the behavior of aggregate price stickiness. To do so, he accomplishes two tasks. First, he endogenizes a measure of aggregate price stickiness (namely, β) in Akerlof and Yellen (1985)'s near-rationality model. He accomplishes this task by introducing a distribution of price-adjustment barriers among the firms into the near-rationality model. More specifically, he assumes that the firms are heterogeneous, instead of being homogeneous or identical, in the sense that they have different price-adjustment barriers, which is, moreover, common knowledge among them.

Then, An (2009) studies the properties of the endogenized β to characterize the behavior of aggregate price stickiness. He obtains three key results. First, he shows that $\lim_{\varepsilon \to 0} \beta(\varepsilon) = 1$, which says that when there is a money supply shock but turns out to be very small, β approaches one. This result intuitively makes sense. Second, he shows that $\left.\frac{d\beta}{d\varepsilon}\right|_{\varepsilon=0} = 0$. As $\left.\frac{d\beta}{d\varepsilon}\right|_{\varepsilon=0} = 0$, then by Taylor's expansion, when ε is very small (close to zero), $\beta(\varepsilon) - \beta(0) = \beta(\varepsilon) - 1 \propto \varepsilon^2$, which says that when the money supply shock is small, almost all the firms will keep their price unchanged, whereas only a "small" fraction that is merely in second-order of the money supply shock will change their price to charge the new optimal price. In other words, prices are not only sticky, but price stickiness is very significant for small money supply shocks in a well-defined sense. Intuitively, only a small fraction of firms will have price-adjustment barriers so small that it pays them to change their price in response to small money supply shocks. Finally, he shows that there exists the possibility of multiple equilibrium values of β. The last result intuitively makes sense. It is due to that following the money supply shock, the profit loss for an individual firm to keep its price unchanged, rather than changing its price to charge the new optimal price, decreases as β increases. In other words, the higher the fraction of the firms that keep their price unchanged following the money supply shock, the less incentive for an individual firm to change its own price. This is exactly the concept of strategic complementarity (Cooper and John, 1988), by which they mean that the optimal strategy of a decision-maker depends positively on the strategies of the other decision-makers. In a word, due to strategic complementarity, the possibility of multiple equilibrium values of β cannot be excluded. The last result also has important implications. The possibility of multiple equilibrium values of β further suggests the possibility of co-ordination failures among the firms. Hence, models with price stickiness (Mankiw, 1985; Akerlof and Yellen, 1985) and models with co-ordination failures (Diamond, 1982) are not completely competing paradigms to explain economic fluctuations, but can be compatible with each other.

In this paper, we study the impact of taxation on aggregate price stickiness in New Keynesian economics. We achieve this by introducing corporate profit taxation into An (2009). We reach three key conclusions. First, we show that the three key results obtained by An (2009) still hold in our extended model. Second, we show that taxation increases aggregate price stickiness. Finally, we show that the magnitude of the impact of taxation on aggregate price stickiness is first-order.

The traditional Keynesian economics focuses entirely on the demand side, and reaches the conclusion that taxes serve as automatic stabilizers on the demand side (for example, Auerbach and Feenberg, 2000; Auerbach, 2009). In sharp contrast, we focus solely on the supply side, and reach the conclusion that taxes contribute to aggregate price stickiness, which suggests that taxes act as automatic destabilizers on the supply side. Hence, the net impact of taxes on economic fluctuations is theoretically ambiguous because in reality, it is obviously a mixture of the supply side effect identified and stressed in this paper and the traditional demand side effect.

Our paper is obviously related with An (2009). Besides, our paper is also related with Kleven and Kreiner (2003), but at least with the following three key differences. First, they still assume that all the firms are homogeneous or identical, whereas we have followed An (2009) to assume that the firms are heterogeneous in the sense that they have different price-adjustment barriers. Second, they still assume that β is exogenous,[6] whereas we have followed An (2009) to endogenize it. Finally, they concentrate on the impact of taxation on an individual firm's profit loss, whereas we directly focus on the impact of taxation on aggregate price stickiness (namely, β). Overall, our paper can be regarded as an integration of An (2009) and Kleven and Kreiner (2003); and more importantly, our paper represents an advancement of both of them.

In a recent important contribution, McKay and Reis (2016) first propose a business cycle model that merges the standard incomplete-market model with the standard New Keynesian business cycle model. They then calibrate it to the U.S. data to measure the effect of the U.S. tax-and-transfer systems on the dynamics of the business cycle. However, they follow Calvo (1983) to assume that firms revise their prices with an exogenously given probability. Hence, they have essentially excluded and ignored the channel identified and emphasized in this paper.

In the immediate wake of the Great Recession, an emerging literature has advanced from the traditional Representative Agent New Keynesian (RANK) framework to the so-called Heterogeneous Agents New Keynesian (HANK) framework that combines key features of heterogeneous agents and New Keynesian economies (for example, Oh and Reis, 2016; McKay and Reis, 2016; Guerrieri and Lorenzoni, 2017; Kaplan et al., 2018). The bulk of this recent

[6] More specifically, they assume that β is equal to a specific value, namely, one by following, for example, Mankiw (1985), Blanchard and Kiyotaki (1987), and Ball and Romer (1989, 1990, and 1991).

literature has focused on the role of household heterogeneity.[7] Our work suggests that the implications of firm heterogeneity should also deserve appropriate attention.

The remainder of the paper is organized as follows. Section II presents the model. Section III illustrates our work using an example. Finally, Section IV briefly concludes the paper.

II. MODEL

An (2009) extends Akerlof and Yellen (1985)'s near-rationality model to endogenize a measure of aggregate price stickiness, namely, the fraction of the firms that keep their price unchanged following a money supply shock, by introducing a distribution of price-adjustment barriers among the firms into the latter. We further extend An (2009)'s model by introducing corporate profit taxation into the latter. Thus, for our exposition to be self-contained, we first review Akerlof and Yellen (1985). Then, we review An (2009). Finally, we base on the two reviews to present our own model.

II.1. A Review of Akerlof and Yellen (1985)

Akerlof and Yellen (1985)'s near-rationality model assumes a monopolistically competitive economy with a fixed number of homogeneous or identical firms. The sales of each firm depend on the level of real aggregate demand and the firm's own price relative to the aggregate price level.

In the initial equilibrium, each firm sets its own price to maximize its own profit, under the assumption that a change in its own price has no effect on the prices charged by rivals or on the aggregate price level. That is, each firm is assumed to be a Bertrand maximizer.

[7] See, for example, Gali (2018) for an assessment of this literature. An exception might be a recent working paper by Ottonello and Winberry (2018) who explore the implications of the firms' financial heterogeneity for the transmission of monetary policy.

Then, Akerlof and Yellen introduce a money supply shock (denoted as ε) into their near-rationality model, where ε is defined as the fractional change in the money supply (denoted as m). That is, they assume that the money supply changes from m to $m(1+\varepsilon)$ with a money supply shock ε. Following the money supply shock, they assume that β fraction of the firms keep their price unchanged, whereas the remaining $(1-\beta)$ fraction of the firms change their price to charge the new optimal price.

If a firm keeps its price unchanged following the money supply shock, rather than changing its price to charge the new optimal price, it would incur a profit loss that is a function of both ε and β. For notational convenience, let us use $L(\varepsilon, \beta)$ to denote this loss function. Akerlof and Yellen have shown that the loss function $L(\varepsilon, \beta)$ has two properties. First, they have shown that $\lim_{\varepsilon \to 0} L(\varepsilon, \beta) = 0$, which says that when there is a money supply shock but turns out to be small, $L(\varepsilon, \beta)$ approaches zero. This result intuitively makes sense. Second, they have also shown that $\left.\frac{\partial L(\varepsilon, \beta)}{\partial \varepsilon}\right|_{\varepsilon=0} = 0$. As $\left.\frac{\partial L(\varepsilon, \beta)}{\partial \varepsilon}\right|_{\varepsilon=0} = 0$, then by Taylor's expansion, when ε is very small (close to zero), $L(\varepsilon, \beta) - L(0, \beta) = L(\varepsilon, \beta) - 0 \propto \varepsilon^2$, which says that $L(\varepsilon, \beta)$ is merely in second-order of ε. Thus, if an individual firm keeps its price unchanged following a money supply shock, its behavior is suboptimal, but still near-rational because its profit loss is merely in second-order of the money supply shock.

Besides, Ball and Romer (1991) have shown that the loss function $L(\varepsilon, \beta)$ has two additional properties, namely, $\left.\frac{\partial L(\varepsilon, \beta)}{\partial \beta}\right|_{\varepsilon=0} = 0$ and $\left.\frac{\partial L(\varepsilon, \beta)}{\partial \beta}\right|_{\varepsilon>0} < 0$. These two properties suggest that following a money supply shock, the profit loss for an individual firm to keep its price unchanged, rather than changing its price to charge the new optimal price, is decreasing in the fraction of the firms that keep their price unchanged (namely, β). In other words, the higher the fraction of the firms that keep their price unchanged following a money supply shock, the less incentive for an individual firm to change its own price. This is exactly the concept of strategic complementarity (Cooper and John, 1988), by which they mean that the optimal strategy of a decision-maker depends positively on the strategies of the other decision-makers.

II.2. A Review of An (2009)

To endogenize the measure of aggregate price stickiness (namely, β) in Akerlof and Yellen (1985)'s near-rationality model, An (2009) keeps intact all the assumptions made in the near-rationality model, except making only one single change. That is, he assumes that the firms are no longer homogeneous or identical, but heterogeneous in the sense that they have different price-adjustment barriers, which is, moreover, common knowledge among them. In other words, he introduces a distribution of price-adjustment barriers among the firms into the near-rationality model.

More specifically, he assumes that each firm has a positive price-adjustment barrier $c_i > 0$, where i is the firm index. The price-adjustment barriers for all the firms (namely, $\{c_i\}$) follow a certain distribution, which is common knowledge among them. For notational convenience, let us use F to denote the cumulative distribution function (CDF) of the price-adjustment barriers. He assumes that F is first-order differentiable and strictly increasing. As $c_i > 0$ for each firm i, he has $F(0) = 0$. As F is first-order differentiable and strictly increasing, he has $F^{'} > 0$, $F^{'}(0_+) > 0$, and $F^{-1'}(0_+) > 0$, where $F^{'}$ and $F^{-1'}$ are the first-order derivative of F and F^{-1} (namely, the inverse function of F), respectively.

Following the money supply shock, each firm would decide whether to change its own price or not. Let us consider a specific firm, saying, firm *i*. When the manager of this firm sets the price following the money supply shock, he would form a rational expectation of the distribution of other firms' price-setting behavior: β fraction of the firms will keep their original optimal price unchanged, whereas the remaining $(1-\beta)$ fraction of the firms will change their price to charge the new optimal price. Why would he form such a rational expectation? A reasonable explanation is: If $L(\varepsilon, \beta) > c_i$, then firm i would change its price to charge the new optimal price; otherwise, firm i would keep its price unchanged, that is, charge the original optimal price. The key point is that $\{c_i\}$ follows a certain distribution, which is common knowledge among the firms. With all the firms following the above behavior, the equilibrium outcome consistent with the rational expectation is that β fraction of the firms would keep their original optimal price unchanged, whereas the remaining $(1-\beta)$ fraction of the firms would change their price to charge the new optimal price. Thus, he reaches the equilibrium equation as follows:

$$1-\beta = F\left(L(\varepsilon,\beta)\right). \tag{1}$$

Equation (1) intuitively makes sense. First, its left hand side (namely, $(1-\beta)$) is, by the definition of β, the fraction of the firms that change their price to charge the new optimal price. Second, its right hand side (namely, $F\left(L(\varepsilon, \beta)\right)$) is, by the definition of F, the fraction of the firms whose price-adjustment barrier is less than $L(\varepsilon, \beta)$, and hence is also the fraction of the firms that change their price to charge the new optimal price. Therefore, the two sides of Equation (1) are equal to each other.

From Equation (1), one can solve for the equilibrium value of β. Thus, An (2009) has endogenized β, a measure of aggregate price stickiness in Akerlof and Yellen (1985)'s near-rationality model.

An (2009) further characterizes the behavior of aggregate price stickiness by studying the properties of the endogenized β. Based on the four properties of the loss function $L(\varepsilon, \beta)$ shown by Akerlof and Yellen (1985) and Ball and Romer (1991), namely, $\lim_{\varepsilon \to 0} L(\varepsilon, \beta) = 0$, $\left.\frac{\partial L(\varepsilon, \beta)}{\partial \varepsilon}\right|_{\varepsilon=0} = 0$, $\left.\frac{\partial L(\varepsilon, \beta)}{\partial \beta}\right|_{\varepsilon=0} = 0$, and $\left.\frac{\partial L(\varepsilon, \beta)}{\partial \beta}\right|_{\varepsilon>0} < 0$, he obtains three key results from Equation (1). First, he shows that $\lim_{\varepsilon \to 0} \beta(\varepsilon) = 1$, which says that when there is a money supply shock but turns out to be very small, β approaches one. This result intuitively makes sense. Second, he shows that $\left.\frac{d\beta}{d\varepsilon}\right|_{\varepsilon=0} = 0$. As $\left.\frac{d\beta}{d\varepsilon}\right|_{\varepsilon=0} = 0$, then by Taylor's expansion, when ε is very small (close to zero), $\beta(\varepsilon) - \beta(0) = \beta(\varepsilon) - 1 \propto \varepsilon^2$, which says that when the money supply shock is small, almost all the firms will keep their price unchanged, whereas only a "small" fraction that is merely in second-order of the money supply shock will change their price to charge the new optimal price. In other words, prices are not only sticky, but price stickiness is very significant for small money supply shocks in a well-defined sense. Intuitively, only a small fraction of firms will have price-adjustment barriers so small that it pays them to change their price in response to small money supply shocks. Finally, he shows that there exists the possibility of multiple equilibrium values of β due to strategic complementarity (Cooper and John, 1988). Intuitively, the higher the fraction of the firms that keep their price unchanged following a money supply shock, the less incentive for an individual firm to change its own price. The possibility of multiple equilibrium values of β has important implications. It further suggests the possibility of co-ordination failures among the firms. Hence, models with price stickiness (Mankiw, 1985; Akerlof and Yellen, 1985) and models with co-ordination failures (Diamond, 1982) are not completely competing paradigms to explain economic fluctuations, but can be compatible with each other.

II.3. Introduce Taxation into An (2009)

Now, let us introduce corporate profit taxation into An (2009). For notational convenience, let us use t to denote the corporate profit tax rate.

As the profit loss for an individual firm to keep its price unchanged following a money supply shock also depends on the corporate profit tax rate t, we accordingly augment the loss function from $L(\varepsilon, \beta)$ to $L(\varepsilon, \beta, t)$. Thus, corresponding to Equation (1), we can write the equilibrium equation for our extended model as follows:

$$1-\beta = F\left(L(\varepsilon, \beta, t)\right). \tag{2}$$

From Equation (2), one can solve for the equilibrium value of β in our extended model.

As the aforementioned four properties of the loss function obtained by Akerlof and Yellen (1985) and Ball and Romer (1991) carry over to our extended model, it is straightforward to follow An (2009) to prove, from Equation (2), that the three results obtained by him still hold in our extended model: (1) $\lim_{\varepsilon\to 0} \beta(\varepsilon) = 1$; (2) $\left.\frac{d\beta}{d\varepsilon}\right|_{\varepsilon=0} = 0$; and (3) there exists the possibility of multiple equilibrium values of β due to strategic complementarity (Cooper and John, 1988).

Kleven and Kreiner (2003) have shown that the loss function has an additional property, namely, $\frac{\partial L(\varepsilon, \beta, t)}{\partial t} < 0$, which says that $L(\varepsilon, \beta, t)$ decreases as t increases. This property intuitively makes sense because corporate profit taxation implies that the government shares the profit loss.

As $\frac{\partial L(\varepsilon, \beta, t)}{\partial t} < 0$, $F^{'} > 0$, and $F^{'}(0_{+}) > 0$, it is also straightforward to prove, from Equation (2), that $\frac{\partial \beta(\varepsilon, t)}{\partial t} > 0$, which has two important implications. First, taxation increases aggregate prices stickiness. Moreover, the magnitude of the impact of taxation on aggregate price stickiness is first-order.

The above two new results we have obtained suggest that taxes act as automatic destabilizers. In sharp contrast, the traditional Keynesian economics show that taxes act as automatic stabilizers (for example, Auerbach and Feenberg, 2000; Auerbach, 2009). However, the sharp contrast can be easily reconciled. It is due to that we focus solely on the supply side, whereas the traditional Keynesian economics concentrates entirely on the demand side.

In reality, the net effect of taxes on economic fluctuations is obviously a mixture of both the supply side effect identified and emphasized in this paper and the traditional demand side effect. Hence, the net effect of taxes on economic fluctuations is theoretically ambiguous.

III. EXAMPLE

In this section, we use an example to illustrate our work. Our example is an extension of the one made by An (2009). That is, we introduce corporate profit taxation into the latter.

Let us consider a monopolist with a constant cost curve and a linear demand curve. Suppose the constant cost is 0 and demand is $q = m - p + \overline{p}$, where m is the money supply, p is the product price of the firm, and $\overline{p}$ is the aggregate price level. In the initial equilibrium, each firm is setting its own price to maximize its own profit, taking the aggregate price level as given. Each individual firm's own price has negligible effect on the aggregate price level. Suppose that the corporate profit tax rate is t.

Now, let us introduce a money supply shock ε, and the money supply changes from m to $m(1+\varepsilon)$. With the money supply shock, the demand curve accordingly becomes: $q = m(1+\varepsilon) - p + \overline{p}$.

For simplicity, we assume that the price-adjustment barriers of the firms follow a uniform distribution $u[0, A]$, which is, moreover, common knowledge among the firms.

Let us assume that following the money supply shock, β fraction of the firms keep their price unchanged, whereas the remaining $(1-\beta)$ fraction of the firms change their price to charge the new optimal price. If the monopolist decides to keep his price unchanged as well, rather than changing his price to charge the new optimal price, he would lose:

$$L = (1-t)m^2(1-x)^2,$$

where $x \equiv \frac{p_m}{m}$, p_m is the new optimal price, L is the loss function, and x satisfies Equation (3):

$$(1+\varepsilon) - 2x + x^{(1-\beta)} = 0. \quad (3)$$

The loss function can be derived by following the same procedures as those in An (2009). The details of how to derive the loss function are available in Appendix 1.

From Equation (3), if $\beta = 1$, then $x = 1 + \frac{\varepsilon}{2}$, and we obtain the minimum loss $L_{\min} = 0.25(1-t)m^2\varepsilon^2$; If $\beta = 0$, then $x = 1+\varepsilon$, and we obtain the maximum loss $L_{\max} = (1-t)m^2\varepsilon^2$. Thus, if $\beta \in [0, 1]$, then $x = 1 + k(\beta)\varepsilon$, and we obtain the general loss function:

$$L(\varepsilon, \beta, t) = (1-t) m^2 (1-x)^2 = (1-t) m^2 \left(k(\beta)\right)^2 \varepsilon^2, \tag{4}$$

where $k(\beta) \in [0.5, 1]$; $\frac{dk(\beta)}{d\beta} < 0$, namely, $k(\beta)$ is strictly decreasing in β**;** and for each $\beta \in [0, 1]$, there is a unique x that satisfies Equation (3), which can be shown graphically by drawing the intersection of function $f(x) = 2x - (1+\varepsilon)$ and function $g(x) = x^{(1-\beta)}$.

Three points can be made from Equation (4). First, from Equation (4), it is straightforward to show that $\lim_{\varepsilon \to 0} L(\varepsilon, \beta, t) = 0$ and $\left.\frac{\partial L(\varepsilon, \beta, t)}{\partial \varepsilon}\right|_{\varepsilon=0} = 0$, namely, the two properties proved by Akerlof and Yellen (1986). As discussed earlier, these two properties suggest that if an individual firm keeps its price unchanged following a money supply shock, its behavior is suboptimal, but still near-rational because its profit loss is merely in second-order of the money supply shock.

Second, from Equation (4), we have $\frac{\partial L(\varepsilon, \beta, t)}{\partial \beta} = 2(1-t) m^2 k(\beta) \varepsilon^2 \frac{dk(\beta)}{d\beta}$. As $\frac{dk(\beta)}{d\beta} < 0$, we thus have $\left.\frac{\partial L(\varepsilon, \beta, t)}{\partial \beta}\right|_{\varepsilon=0} = 0$ and $\left.\frac{\partial L(\varepsilon, \beta, t)}{\partial \beta}\right|_{\varepsilon>0} < 0$, namely, the two properties proved by Ball and Romer (1991). As discussed earlier, these two properties suggest that following a money supply shock, the profit loss for an individual firm to keep its price unchanged, rather than changing its price to charge the new optimal price, is decreasing in the fraction of the firms that keep their price unchanged (namely, β). In other words, the higher the fraction of the firms that keep their price unchanged following a money supply shock, the less incentive for an individual firm to change its own price. This is exactly the concept of strategic complementarity (Cooper and John, 1988), by which they mean that the optimal strategy of a decision-maker depends positively on the strategies of the other decision-makers.

In summary, the first two points suggest that the four properties of the loss function obtained by Akerlof and Yellen (1985) and Ball and Romer (1991) carry over to our extended model. Thus, it is straightforward to follow An (2009) to prove, from Equation (2), that the three results obtained by him still hold in our extended model: (1) $\lim_{\varepsilon \to 0} \beta(\varepsilon) = 1$; (2) $\left. \frac{d\beta}{d\varepsilon} \right|_{\varepsilon=0} = 0$; and (3) there exists the possibility of multiple equilibrium values of β due to strategic complementarity (Cooper and John, 1988).

Finally, from Equation (4), it is straightforward to prove that $\frac{\partial L(\varepsilon, \beta, t)}{\partial t} = -m^2 \left(k\left(\beta\right)\right)^2 \varepsilon^2 < 0$, namely, the property obtained by Kleven and Kreiner (2003). This result intuitively makes sense because corporate profit taxation implies that the government shares the profit loss.

Because $1-\beta = F\left(L\left(\varepsilon, \beta, t\right)\right)$ and the price-adjustment barriers follow the uniform distribution $u[0, A]$, namely, $F\left(y\right) = \frac{y}{A}$ for $\forall y \in [0, A]$, we have:

$$\beta = 1 - \frac{\left(1-t\right) m^2 \left(k(\beta)\right)^2 \varepsilon^2}{A} . \tag{5}$$

As $\frac{dk\left(\beta\right)}{d\beta} < 0$, it is straightforward to prove, from Equation (5), that $\frac{\partial \beta\left(\varepsilon, t\right)}{\partial t} > 0$, which says that taxation increases aggregate price stickiness; and moreover, the magnitude of the impact of taxation on aggregate price stickiness is first-order.

IV. CONCLUSION

In this paper, we study the impact of taxation on aggregate price stickiness in New Keynesian economics. We show that taxation contributes to aggregate price stickiness. Moreover, we show that the magnitude of the impact of taxation on aggregate price stickiness is first-order. Our results suggest that taxes act as automatic destabilizers on the supply side, which is in sharp contrast with the idea of traditional Keynesian economics that taxes act as automatic stabilizers on the demand side. Hence, the net effect of taxes on economic fluctuations is theoretically ambiguous because in reality, it is obviously a mixture of both the supply side effect identified and emphasized in this paper and the traditional demand side effect.

APPENDIX 1.

In the initial equilibrium, each firm sets its own price to maximize its own profit, taking the aggregate price level as given. Essentially, each firm must solve the following maximization problem, taking the aggregate price level as given: $\max_{\{p\}} \ (1-t)\, p\left(m - p + \overline{p}\right)$. The first-order condition for this optimization problem is:

$$m - 2p + \overline{p} = 0\,. \tag{A1}$$

As each firm is charging the same price, we have:

$$\overline{p} = p\,. \tag{A2}$$

From Equations (A1) and (A2), we have: $\overline{p} = p = m$.

Now, let us introduce a money supply shock ε, and the money supply changes from m to $m(1+\varepsilon)$. Following the money supply shock, we assume that β fraction of the firms keep their original optimal price unchanged, that is, their price is still m. However, the remaining $(1-\beta)$ fraction of the firms change their price to charge the new optimal price. Essentially, they must solve the following maximization problem, taking the new aggregate price level as given: $\max_{\{p_m\}} \ (1-t)\, p_m\left(m(1+\varepsilon) - p_m + \overline{p}_{new}\right)$, where $\overline{p}_{new}$ is the new aggregate price level. The first-order condition for this optimization problem is:

$$m(1+\varepsilon) - 2p_m + \overline{p}_{new} = 0\,. \tag{A3}$$

Following the money supply shock, β fraction of the firms continue to charge m, whereas the remaining $(1-\beta)$ fraction of the firms change their price to charge p_m. By the definition of aggregate price level, we thus have:

$$\overline{p}_{new} = m^{\beta}\, p_m^{1-\beta}\,. \tag{A4}$$

Substituting Equation (A4) into Equation (A3), we have:

$$m(1+\varepsilon)-2p_m + m^{\beta} p_m^{1-\beta} = 0. \tag{A5}$$

Let us define: $x \equiv \dfrac{p_m}{m}$. Then, we can rewrite Equation (A5) as follows:

$$(1+\varepsilon)-2x + x^{(1-\beta)} = 0. \tag{A6}$$

Now, we can write down the loss function:

$$L(\varepsilon,\beta,t)=(1-t)\,p_m\left(m(1+\varepsilon)-p_m+\overline{p}_{new}\right)-(1-t)\,m\left(m(1+\varepsilon)-m+\overline{p}_{new}\right). \tag{A7}$$

Substituting Equations (A4) and (A5) into Equation (A7), we have:

$$L(\varepsilon,\beta,t)=(1-t)(m-p_m)^2. \tag{A8}$$

As $x \equiv \dfrac{p_m}{m}$, we can rewrite Equation (A8) as $L(\varepsilon,\beta,t)=(1-t)m^2(1-x)^2$, where x satisfies Equation (A6). Thus, we have derived the loss function $L(\varepsilon,\beta,t)$ in our example.

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