

Euler-Phillips system would be a saddle in the NK model and a source in the WUNK model.

For completeness, we also plot sample solutions to the Euler-Phillips system. The trajectories are obtained by linearizing the Euler-Phillips system at its steady state.⁷ When the system is a source, there are two unstable lines (trajectories that move away from the steady state in a straight line). At $t \rightarrow -\infty$, all other trajectories are in the vicinity of the steady state and move away tangentially to one of the unstable lines. At $t \rightarrow +\infty$, the trajectories move to infinity parallel to the other unstable line. When the system is a saddle, there is one unstable line and one stable line (trajectory that goes to the steady state in a straight line). All other trajectories come from infinity parallel to the stable line when $t \rightarrow -\infty$ and move to infinity parallel to the unstable line when $t \rightarrow +\infty$.

The next propositions summarize the results:

Proposition 1. *Consider the Euler-Phillips system in normal times. The system admits a unique steady state, where output is at its natural level, inflation is 0, and the ZLB is not binding. In the NK model, the system is a source when monetary policy is active but a saddle when monetary policy is passive. In the WUNK model, the system is a source whether monetary policy is active or passive.*

Proposition 2. *Consider the Euler-Phillips system at the ZLB. In the NK model, the system admits a unique steady state, where output is above its natural level and inflation is positive; furthermore, the system is a saddle. In the WUNK model, the system admits a unique steady state, where output is below its natural level and inflation is negative; furthermore, the system is a source.*

The propositions give the key difference between the NK and WUNK models: at the ZLB, the Euler-Phillips system remains a source in the WUNK model, whereas it becomes a saddle in the NK model. This difference will explain why the WUNK model does not suffer from the anomalies plaguing the NK model at the ZLB. The phase diagrams also illustrate the origin of condition (9). In the WUNK model, the Euler-Phillips system remains a source at the ZLB as long as the Euler line is steeper than the Phillips line (figure 1D). The Euler line's slope at the ZLB is the marginal utility of wealth, so that marginal utility is required to be above a certain level—which is given by condition (9).

The propositions have implications for equilibrium determinacy. When the Euler-Phillips system is a source, the equilibrium is determinate: the only equilibrium trajectory in the vicinity of the steady state is to jump to the steady state and stay there; if the economy jumped somewhere else, output or inflation would diverge following a trajectory similar to those plotted in figures 1A, 1B, and 1D. When the system is a saddle, the equilibrium is indeterminate: any trajectory jumping somewhere on the saddle path and converging to the steady state is an equilibrium (figure 1C). Hence, in the NK

model, the equilibrium is determinate when monetary policy is active but indeterminate when monetary policy is passive and at the ZLB. In the WUNK model, the equilibrium is always determinate, even when monetary policy is passive and at the ZLB.

Accordingly, in the NK model, the Taylor principle holds: the central bank must adhere to an active monetary policy to avoid indeterminacy. From now on, we therefore assume that the central bank in the NK model follows an active policy whenever it can ($\phi > 1$ whenever $r^n > 0$). In the WUNK model, by contrast, indeterminacy is never a risk, so the central bank does not need to worry about how strongly its policy rate responds to inflation. The central bank could even follow an interest-rate peg without creating indeterminacy.

The results that pertain to the NK model in propositions 1 and 2 are well known (Woodford, 2001). The results that pertain to the WUNK model are close to those obtained by Gabaix (2016, proposition 3.1), although he does not use our phase-diagram representation. Gabaix finds that when bounded rationality is strong enough, the Euler-Phillips system is a source even at the ZLB. He also finds that when prices are more flexible, more bounded rationality is required to maintain the source property. The same is true here: when the marginal utility of wealth is high enough, such that condition (9) holds, the Euler-Phillips system is a source even at the ZLB; and when the price-adjustment cost γ is lower, condition (9) imposes a higher threshold on the marginal utility of wealth. Our phase diagrams illustrate the logic behind these results. The Euler-Phillips system remains a source at the ZLB as long as the Euler line is steeper than the Phillips line (figure 1D). As the slope of the Euler line is determined by bounded rationality in the Gabaix model and by marginal utility of wealth in our model, these need to be large enough. When prices are more flexible, the Phillips line steepens, so the Euler line's required steepness increases: bounded rationality or marginal utility of wealth need to be larger.

IV. Description and Resolution of the New Keynesian Anomalies

We now describe the anomalous predictions of the NK model at the ZLB: an implausibly large drop in output and inflation and implausibly strong effects of forward guidance and government spending. We then show that these anomalies are absent from the WUNK model.

A. Drop in Output and Inflation

We consider a temporary ZLB episode, as in Werning (2011). Between times 0 and $T > 0$, the natural rate of interest is negative. In response, the central bank maintains its policy rate at 0. After time T , the natural rate is positive again, and monetary policy returns to normal. This scenario is summarized in table 1A. We analyze the ZLB episode using the phase diagrams in figure 2.

⁷Technically the trajectories only approximate the exact solutions, but the approximation is accurate in the neighborhood of the steady state.

TABLE 1.—ZLB SCENARIOS

	Timeline	Natural Rate of Interest	Monetary Policy	Government Spending
A. ZLB episode				
ZLB	$t \in (0, T)$	$r^n < 0$	$i = 0$	—
Normal times	$t > T$	$r^n > 0$	$i = r^n + \phi\pi$	—
B. ZLB episode with forward guidance				
ZLB	$t \in (0, T)$	$r^n < 0$	$i = 0$	—
Forward guidance	$t \in (T, T + \Delta)$	$r^n > 0$	$i = 0$	—
Normal times	$t > T + \Delta$	$r^n > 0$	$i = r^n + \phi\pi$	—
C. ZLB episode with government spending				
ZLB	$t \in (0, T)$	$r^n < 0$	$i = 0$	$g > 0$
Normal times	$t > T$	$r^n > 0$	$i = r^n + \phi\pi$	$g = 0$

This table describes the three scenarios analyzed in section IV: the ZLB episode, in section IVA; the ZLB episode with forward guidance, in section IVB; and the ZLB episode with government spending, in section IVC. The parameter $T > 0$ gives the duration of the ZLB episode; the parameter $\Delta > 0$ gives the duration of forward guidance. We assume that monetary policy is active ($\phi > 1$) in normal times in the NK model; this assumption is required to ensure equilibrium determinacy (Taylor principle). In the WUNK model, monetary policy can be active or passive in normal times.

We start with the NK model. We analyze the ZLB episode by going backward in time. After time T , monetary policy maintains the economy at the natural steady state. Since equilibrium trajectories are continuous, the economy also is at the natural steady state at the end of the ZLB, when $t = T$.⁸

We then move back to the ZLB episode, when $t < T$. At time 0, the economy jumps to the unique position leading to $[y = y^n, \pi = 0]$ at time T . Hence, inflation and output initially jump down to $\pi(0) < 0$ and $y(0) < y^n$, and then recover following the unique trajectory leading to $[y = y^n, \pi = 0]$. The ZLB therefore creates a slump, with below-natural output and deflation (figure 2A).

Critically, the economy is always on the same trajectory during the ZLB, irrespective of the ZLB duration T . A longer ZLB only forces output and inflation to start from a lower position on the trajectory at time 0. Thus, as the ZLB lasts longer, initial output and inflation collapse to unboundedly low levels (figure 2C).

Next, we examine the WUNK model. Output and inflation never collapse during the ZLB. Initially inflation and output jump down toward the ZLB steady state, denoted $[y^z, \pi^z]$, so $\pi^z < \pi(0) < 0$ and $y^z < y(0) < y^n$. They then recover following the trajectory going through $[y = y^n, \pi = 0]$. Consequently the ZLB episode creates a slump (figure 2B), which is deeper when the ZLB lasts longer (figure 2D). But unlike in the NK model, the slump is bounded below by the ZLB steady state: irrespective of the duration of the ZLB, output and inflation remain above y^z and π^z , respectively, so they never collapse. Moreover, if the natural rate of interest is negative but close to 0, such that π^z is close to 0 and y^z to y^n , output and inflation will barely deviate from the natural steady state during the ZLB—even if the ZLB lasts a very long time.

⁸The trajectories are continuous in output and inflation because households have concave preferences over the two arguments. If consumption had an expected discrete jump, for example, households would be able to increase their utility by reducing the size of the discontinuity.

The following proposition records these results:⁹

Proposition 3. *Consider a ZLB episode between times 0 and T . The economy enters a slump: $y(t) < y^n$ and $\pi(t) < 0$ for all $t \in (0, T)$. In the NK model, the slump becomes infinitely severe as the ZLB duration approaches infinity: $\lim_{T \rightarrow \infty} y(0) = \lim_{T \rightarrow \infty} \pi(0) = -\infty$. In the WUNK model, in contrast, the slump is bounded below by the ZLB steady state $[y^z, \pi^z]$: $y(t) > y^z$ and $\pi(t) > \pi^z$ for all $t \in (0, T)$. In fact, the slump approaches the ZLB steady state as the ZLB duration approaches infinity: $\lim_{T \rightarrow \infty} y(0) = y^z$ and $\lim_{T \rightarrow \infty} \pi(0) = \pi^z$.*

In the NK model, output and inflation collapse when the ZLB is long-lasting, which is well known (Eggertsson & Woodford, 2004, fig. 1; Eggertsson, 2011, fig. 1; Werning, 2011, proposition 1). This collapse is difficult to reconcile with real-world observations. The ZLB episode that started in 1995 in Japan lasted for more than twenty years without sustained deflation. The ZLB episode that started in 2009 in the euro area lasted for more than ten years; it did not yield sustained deflation either. The same is true of the ZLB episode that occurred in the United States between 2008 and 2015.

In the WUNK model, in contrast, inflation and output never collapse. Instead, as the duration of the ZLB increases, the economy converges to the ZLB steady state. That ZLB steady state may not be far from the natural steady state: if the natural rate of interest is only slightly negative, inflation is only slightly below 0 and output only slightly below its natural level. Gabaix (2016, proposition 3.2) obtains a closely related result: in his model, output and inflation also converge to the ZLB steady state when the ZLB is arbitrarily long.

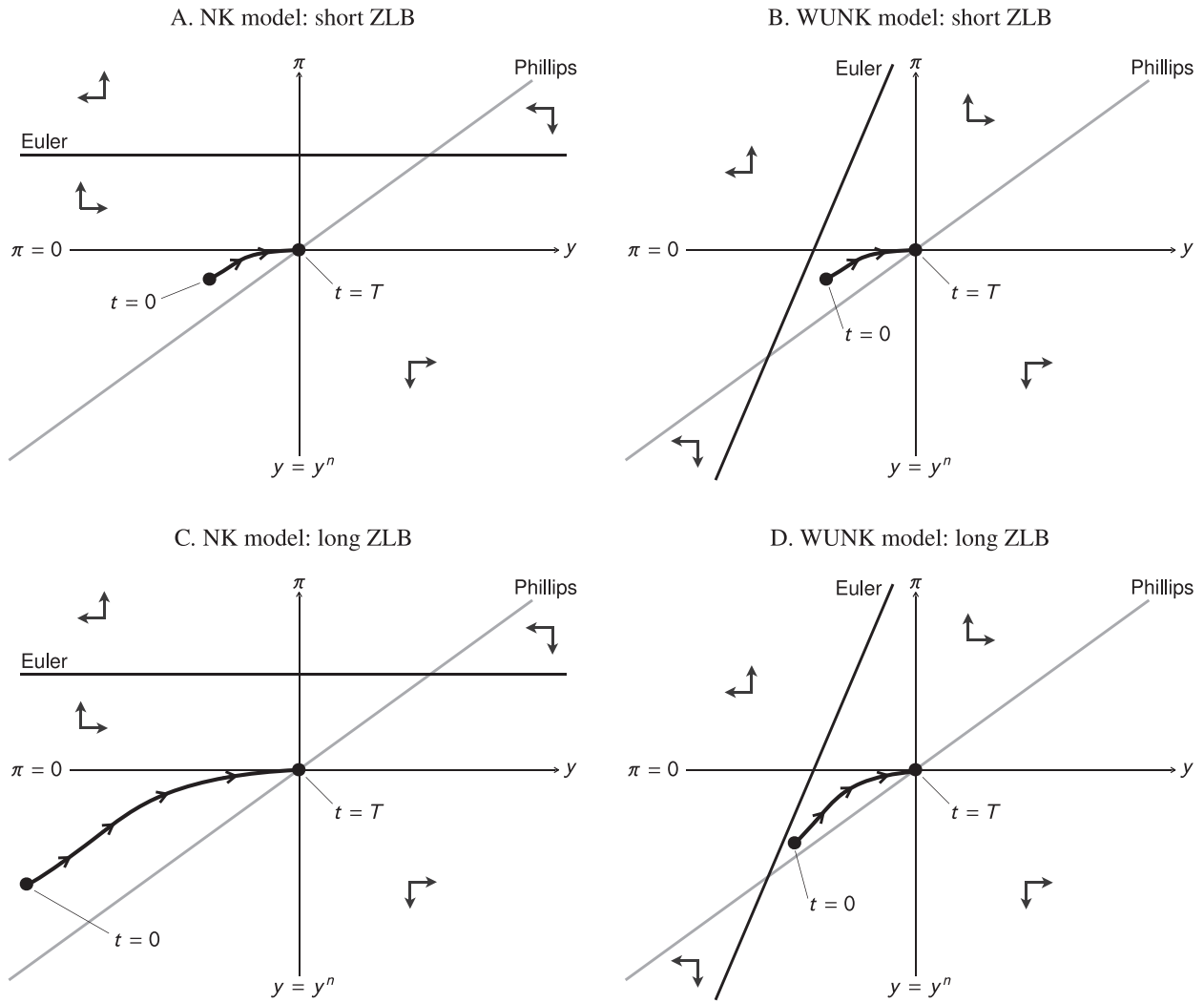
B. Forward Guidance

We turn to the effects of forward guidance at the ZLB. We consider a three-stage scenario, as in Cochrane (2017). Between times 0 and T , there is a ZLB episode. To alleviate the situation, the central bank makes a forward-guidance promise at time 0: that it will maintain the policy rate at 0 for a duration Δ once the ZLB is over. After time T , the natural rate of interest is positive again. Between times T and $T + \Delta$, the central bank fulfills its forward-guidance promise and keeps the policy rate at 0. After time $T + \Delta$, monetary policy returns to normal. This scenario is summarized in table 1B.

We analyze the ZLB episode with forward guidance using the phase diagrams in figures 3 and 4. The forward-guidance diagrams are based on the ZLB diagrams in figure 1. In the NK model (figure 3A), the diagram is the same as in figure 1C, except that the Euler line, given by $\pi = -r^n$, is lower because $r^n > 0$ instead of $r^n < 0$. In the WUNK model (figure 4A), the diagram is the same as in figure 1D, except that the Euler

⁹The result that in the NK model output becomes infinitely negative when the ZLB becomes infinitely long should not be interpreted literally. It is obtained because we omitted the constraint that output must remain positive. The proper interpretation is that output falls much, much below its natural level—in fact, it converges to 0.

FIGURE 2.—ZLB EPISODES IN THE NK AND WUNK MODELS



The timeline of a ZLB episode is presented in table 1A. The phase diagram of the NK model comes from figure 1C. The phase diagram of the WUNK model comes from figure 1D. The equilibrium trajectories are the unique trajectories reaching the natural steady state (where $\pi = 0$ and $y = y^n$) at time T . The figure shows that the economy slumps during the ZLB: inflation is negative, and output is below its natural level (A, B). In the NK model, the initial slump becomes unboundedly severe as the ZLB lasts longer (C). In the WUNK model, there is no such collapse: output and inflation are bounded below by the ZLB steady state (D).

line, given by equation (10), is shifted outward because $r^n > 0$ instead of $r^n < 0$.

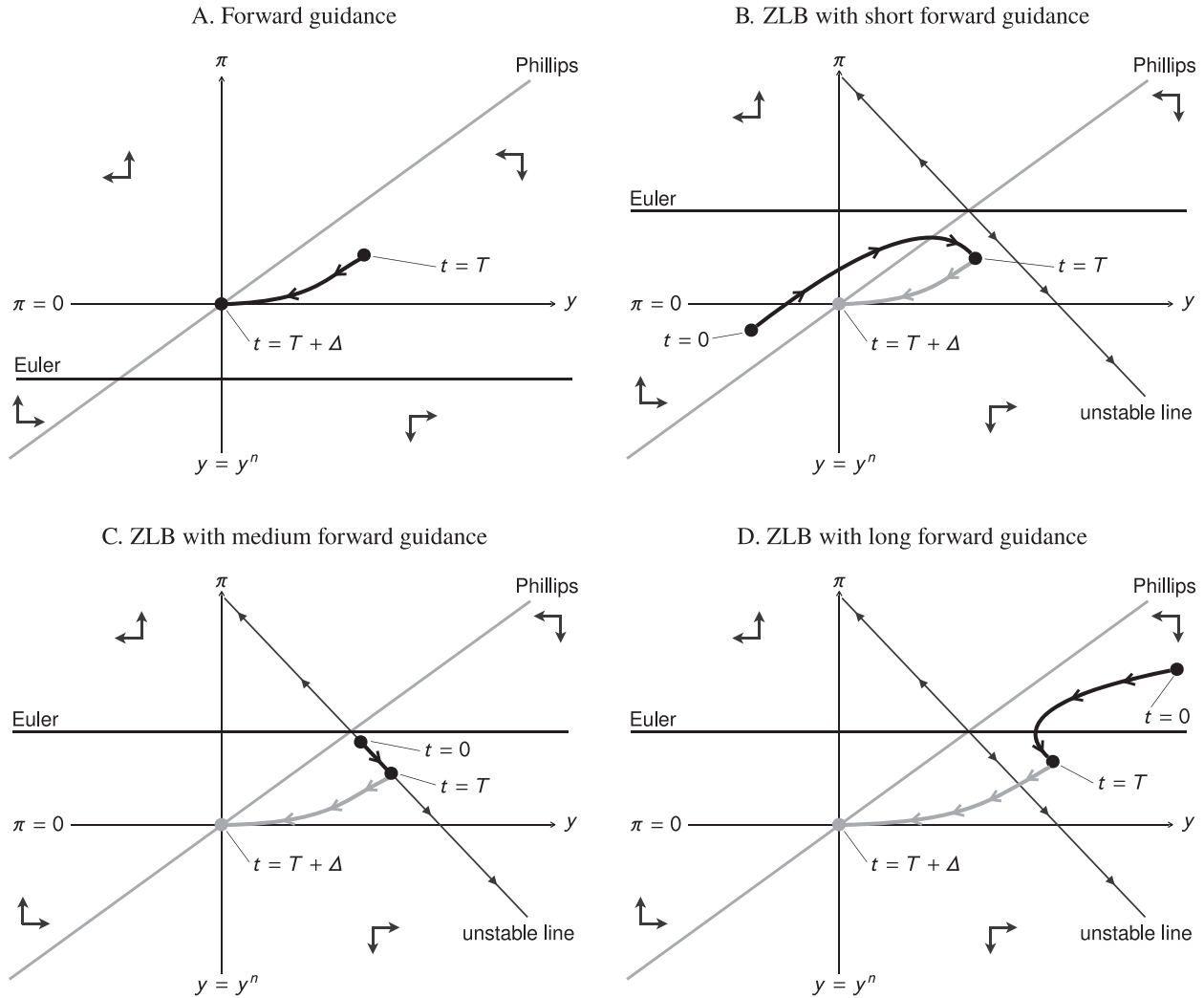
We begin with the NK model. We go backward in time. After time $T + \Delta$, monetary policy maintains the economy at the natural steady state. Between times T and $T + \Delta$, the economy is in forward guidance (figure 3A). Following the logic of figure 2, we find that at time T , inflation is positive and output above its natural level. They subsequently decrease over time, following the unique trajectory leading to the natural steady state at time $T + \Delta$. Accordingly, the economy booms during forward guidance. Furthermore, as forward guidance lengthens, inflation and output at time T become higher.

We look next at the ZLB episode, between times 0 and T . Since equilibrium trajectories are continuous, the economy is at the same point at the end of the ZLB and the beginning of forward guidance. The boom engineered during forward guidance therefore improves the situation at the ZLB. Instead

of reaching the natural steady state at time T , the economy reaches a point with positive inflation and above-natural output, so at any time before T , inflation and output tend to be higher than without forward guidance (figure 3B).

Forward guidance can actually have tremendously strong effects in the NK model. For small durations of forward guidance, the position at time T is below the ZLB unstable line. It is therefore connected to trajectories coming from the southwest quadrant of the phase diagram (figure 3B). As the ZLB lasts longer, initial output and inflation collapse. When the duration of forward guidance is such that the position at time T is exactly on the unstable line, the position at time 0 is on the unstable line as well (figure 3C). As the ZLB lasts longer, the initial position inches closer to the ZLB steady state. For even longer forward guidance, the position at time T is above the unstable line, so it is connected to trajectories coming from the northeast quadrant (figure 3D). Then, as the ZLB lasts longer, initial output and inflation become higher

FIGURE 3.—NK MODEL: ZLB EPISODES WITH FORWARD GUIDANCE



The timeline of ZLB episodes with forward guidance is presented in table 1B. (A) The phase diagram of the NK model during forward guidance is similar to the diagram in figure 1C, but with $r^n > 0$. The equilibrium trajectory during forward guidance is the unique trajectory reaching the natural steady state at time $T + \Delta$. (B–D) The phase diagram of the NK model at the ZLB comes from figure 1C. The equilibrium trajectory at the ZLB is the unique trajectory reaching the point determined by forward guidance at time T . The figure shows that the NK model suffers from an anomaly: when forward guidance lasts sufficiently to bring $[y(T), \pi(T)]$ above the unstable line, any ZLB episode—however long—triggers a boom (D). On the other hand, if forward guidance is short enough to keep $[y(T), \pi(T)]$ below the unstable line, long-enough ZLB episodes are slumps (B). In the knife-edge case where $[y(T), \pi(T)]$ falls just on the unstable line, arbitrarily long ZLB episodes converge to the ZLB steady state (C).

and higher. As a result, if the duration of forward guidance is long enough, a deep slump can be transformed into a roaring boom. Moreover, the forward-guidance duration threshold is independent of the ZLB duration.

In comparison, the power of forward guidance is subdued in the WUNK model. Between times T and $T + \Delta$, forward guidance operates (figure 4A). Inflation is positive, and output is above its natural level at time T . They then decrease over time, following the trajectory leading to the natural steady state at time $T + \Delta$. The economy booms during forward guidance, but unlike in the NK model, output and inflation are bounded above by the forward-guidance steady state.

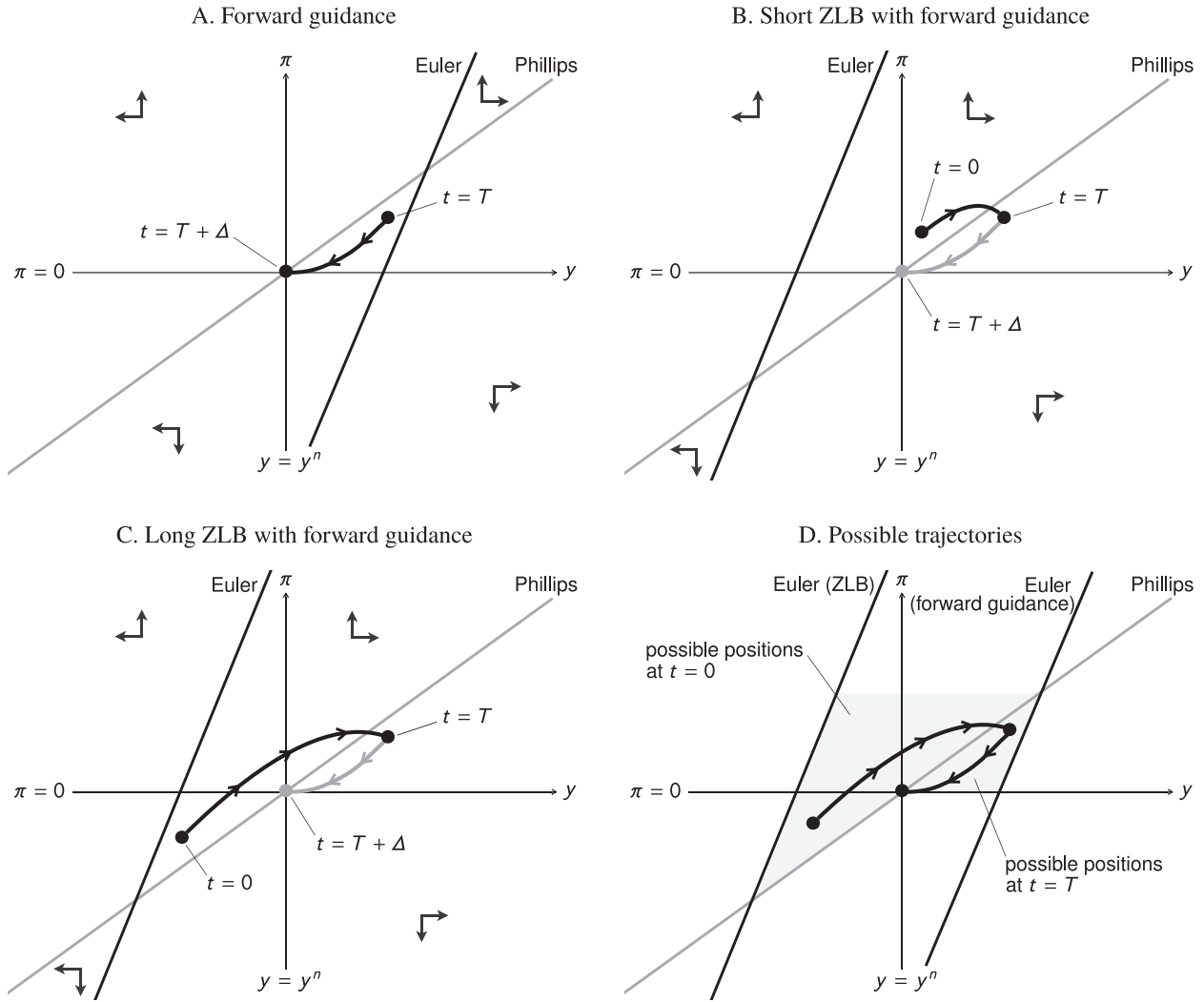
Before forward guidance comes the ZLB episode (figures 4B and 4C). Thanks to the boom engineered by forward guidance, the situation is improved at the ZLB: inflation and output tend to be higher than without forward

guidance. Yet, unlike in the NK model, output during the ZLB episode is always below its level at time T , so forward guidance cannot generate unbounded booms (figure 4D). The ZLB cannot generate unbounded slumps either, since output and inflation are bounded below by the ZLB steady state (figure 4D). Actually, for any forward-guidance duration, as the ZLB lasts longer, the economy converges to the ZLB steady state at time 0. The implication is that forward guidance can never prevent a slump when the ZLB lasts long enough.

Based on these dynamics, we identify an anomaly in the NK model, which is resolved in the WUNK model (proof details in online appendix D):

Proposition 4. Consider a ZLB episode during $(0, T)$ followed by forward guidance during $(T, T + \Delta)$:

FIGURE 4.—WUNK MODEL: ZLB EPISODES WITH FORWARD GUIDANCE



The timeline of ZLB episodes with forward guidance is presented in table 1B. (A) The phase diagram of the WUNK model during forward guidance is similar to the diagram in figure 1D, but with $r^n > 0$. The equilibrium trajectory during forward guidance is the unique trajectory reaching the natural steady state at time $T + \Delta$. (B, C) The phase diagram of the WUNK model at the ZLB comes from figure 1D. The equilibrium trajectory at the ZLB is the unique trajectory reaching the point determined by forward guidance at time T . The figure shows that the NK model’s anomaly disappears in the WUNK model: a long-enough ZLB episode prompts a slump irrespective of the duration of forward guidance.

- In the NK model, there exists a threshold Δ^* such that a forward guidance longer than Δ^* transforms a ZLB episode of any duration into a boom: let $\Delta > \Delta^*$; for any T and for all $t \in (0, T + \Delta)$, $y(t) > y^n$ and $\pi(t) > 0$. In addition, when forward guidance is longer than Δ^* , a long-enough forward guidance or ZLB episode generates an arbitrarily large boom: for any T , $\lim_{\Delta \rightarrow \infty} y(0) = \lim_{\Delta \rightarrow \infty} \pi(0) = +\infty$; and for any $\Delta > \Delta^*$, $\lim_{T \rightarrow \infty} y(0) = \lim_{T \rightarrow \infty} \pi(0) = +\infty$.
- In the WUNK model, in contrast, there exists a threshold T^* such that a ZLB episode longer than T^* prompts a slump, irrespective of the duration of forward guidance: let $T > T^*$; for any Δ , $y(0) < y^n$ and $\pi(0) < 0$. Furthermore, the slump approaches the ZLB steady state as the ZLB duration approaches infinity: for any Δ , $\lim_{T \rightarrow \infty} y(0) = y^z$ and $\lim_{T \rightarrow \infty} \pi(0) = \pi^z$. In addition, the economy is bounded above by the forward-guidance

steady state $[y^f, \pi^f]$: for any T and Δ , and for all $t \in (0, T + \Delta)$, $y(t) < y^f$ and $\pi(t) < \pi^f$.

The anomaly identified in the proposition corresponds to the forward-guidance puzzle described by Carlstrom, Fuerst, and Paustian (2015, fig. 1) and Cochrane (2017, fig. 6).¹⁰ These papers also find that a long-enough forward guidance transforms a ZLB slump into a boom.

In the WUNK model, this anomalous pattern vanishes. In the New Keynesian models by Gabaix (2016), Diba and Loisel (2019), Acharya and Dogra (2019), and Bilbie (2019), forward guidance also has more subdued effects than in the standard model. Besides, New Keynesian models have been developed with the sole goal of solving the

¹⁰In the literature, the forward-guidance puzzle takes several forms. The common element is that future monetary policy has an implausibly strong effect on current output and inflation.

forward-guidance puzzle. Among these, ours belongs to the group that uses discounted Euler equations.¹¹ For example, Del Negro, Giannoni, and Patterson (2015) generate discounting from overlapping generations; McKay, Nakamura, and Steinsson (2016) from heterogeneous agents facing borrowing constraints and cyclical income risk; Angeletos and Lian (2018) from incomplete information; and Campbell et al. (2017) from government bonds in the utility function (which is closely related to our approach).

C. Government Spending

Finally, we consider the effects of government spending at the ZLB. We first extend the model by assuming that the government purchases goods from all households, which are aggregated into public consumption $g(t)$. To ensure that government spending affects inflation and private consumption, we also assume that the disutility of labor is convex: household j incurs disutility $\kappa^{1+\eta} h_j(t)^{1+\eta}/(1+\eta)$ from working, where $\eta > 0$ is the inverse of the Frisch elasticity. The complete extended model, derivations, and results are presented in online appendix E.

In this model, the Euler equation is unchanged, but the Phillips curve is modified because the marginal disutility of labor is not constant and because households produce goods for the government. The modification of the Phillips curve alters the analysis in three ways.

First, the steady-state Phillips curve becomes nonlinear, which may introduce additional steady states. We handle this issue as in the literature: we linearize the Euler-Phillips system around the natural steady state without government spending and concentrate on the dynamics of the linearized system. These dynamics are described by phase diagrams similar to those in the basic model.

Second, the slope of the steady-state Phillips curve is modified, so the WUNK assumption needs to be adjusted. Instead of equation (3), the linearized steady-state Phillips curve is

$$\pi = -\frac{\epsilon\kappa}{\delta\gamma a} \left(\frac{\epsilon-1}{\epsilon}\right)^{\eta/(1+\eta)} (1+\eta)(c-c^n) + \eta g. \quad (11)$$

The WUNK assumption guarantees that at the ZLB, the steady-state Euler equation, with slope $u'(0)$, is steeper than the steady-state Phillips curve, now given by equation (11). Hence, we need to replace condition (9) by

$$u'(0) > (1+\eta) \frac{\epsilon\kappa}{\delta\gamma a} \left(\frac{\epsilon-1}{\epsilon}\right)^{\eta/(1+\eta)}. \quad (12)$$

Naturally, for $\eta = 0$, this condition reduces to (9).

Third, public consumption enters the Phillips curve, so government spending operates through that curve. Indeed, since $\eta > 0$ in equation (11), government spending shifts the steady-state Phillips curve upward. Intuitively, given private consumption, an increase in government spending raises production and thus marginal costs. Facing higher marginal costs, producers augment inflation.

We now study a ZLB episode during which the government increases spending in an effort to stimulate the economy, as in Cochrane (2017). Between times 0 and T , there is a ZLB episode. To alleviate the situation, the government provides an amount $g > 0$ of public consumption. After time T , the natural rate of interest is positive again, government spending stops, and monetary policy returns to normal. This scenario is summarized in table 1C.

We start with the NK model (see figure 5).¹² We construct the equilibrium path by going backward in time. At time T , monetary policy brings the economy to the natural steady state. At the ZLB, government spending helps, but through a different mechanism from forward guidance. Forward guidance improves the situation at the end of the ZLB, which pulls up the economy during the entire ZLB. Government spending leaves the end of the ZLB unchanged: the economy reaches the natural steady state. Instead, government spending shifts the Phillips line upward and, with it, the field of trajectories. As a result, the natural steady state is connected to trajectories with higher consumption and inflation, which improves the situation during the entire ZLB.

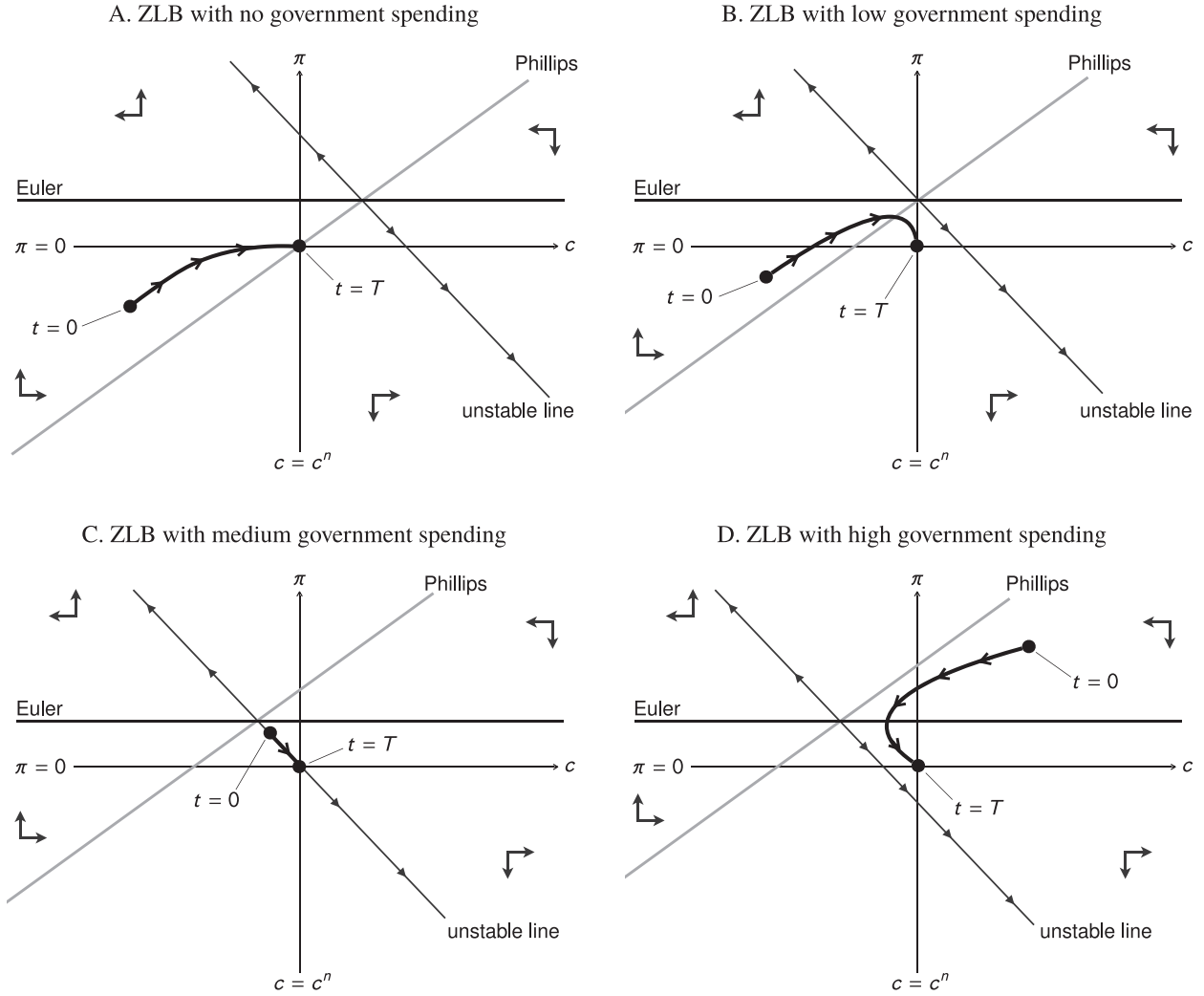
Just like forward guidance, government spending can have very strong effects in the NK model. When spending is low, the natural steady state is below the ZLB unstable line (figure 5B). It is therefore connected to trajectories coming from the southwest quadrant of the phase diagram—just as without government (figure 5A). Then, if the ZLB lasts longer, initial consumption and inflation fall lower. When spending is high enough that the unstable line crosses the natural steady state, the economy is also on the unstable line at time 0 (figure 5C). Finally, when spending is even higher, the natural steady state moves above the unstable line, so it is connected to trajectories coming from the northeast quadrant (figure 5D). As a result, initial output and inflation are higher than previously. And as the ZLB lasts longer, initial output and inflation become even higher, without bound.

The power of government spending at the ZLB is much weaker in the WUNK model (see figure 6). Government spending does improve the situation at the ZLB, as inflation and consumption tend to be higher than without spending. But as the ZLB lasts longer, the position at the beginning of the ZLB converges to the ZLB steady state; unlike in the NK model, it does not go to infinity. So equilibrium

¹¹Other approaches to solve the forward-guidance puzzle include modifying the Phillips curve (Carlstrom, Fuerst, & Paustian, 2015), combining reflective expectations and temporary equilibrium (Garcia-Schmidt & Woodford, 2019), combining bounded rationality and incomplete markets (Farhi & Werning, 2019), and introducing an endogenous liquidity premium (Bredemeier, Kaufmann, & Schabert, 2018).

¹²There is a small difference with the phase diagrams of the basic model: private consumption c is on the horizontal axis instead of output y . But $y = c$ in the basic model (government spending is 0), so the phase diagrams with private consumption on the horizontal axis would be the same as those with output.

FIGURE 5.—NK MODEL: ZLB EPISODES WITH GOVERNMENT SPENDING



The timeline of ZLB episodes with government spending is presented in table 1C. The figure displays the phase diagrams of the linearized Euler-Phillips system for the NK model with government spending and convex disutility of labor at the ZLB: c is private consumption; π is inflation; c^n is the natural level of private consumption; the Euler line is the locus $\dot{c} = 0$; the Phillips line is the locus $\dot{\pi} = 0$. The phase diagrams have the same properties as that in figure 1C, except that the Phillips line shifts upward when government spending increases (see equation (11)). The equilibrium trajectory at the ZLB is the unique trajectory reaching the natural steady state at time T . The figure shows that the NK model suffers from an anomaly. When government spending brings down the unstable line from above to below the natural steady state, an arbitrarily long ZLB episode sees an arbitrarily large increase in output, which triggers an unboundedly large boom (from B to D). On the other hand, if government spending is low enough to keep the unstable line above the natural steady state, long-enough ZLB episodes are slumps (B). In the knife-edge case where the natural steady state falls just on the unstable line, arbitrarily long ZLB episodes converge to the ZLB steady state (C).

trajectories are bounded, and government spending cannot generate unbounded booms.

Based on these dynamics, we isolate another anomaly in the NK model, which is resolved in the WUNK model (proof details in online appendix F):

Proposition 5. Consider a ZLB episode during $(0, T)$, accompanied by government spending $g > 0$. Let $c(t; g)$ and $y(t; g)$ be private consumption and output at time t ; let $s > 0$ be some incremental government spending; and let

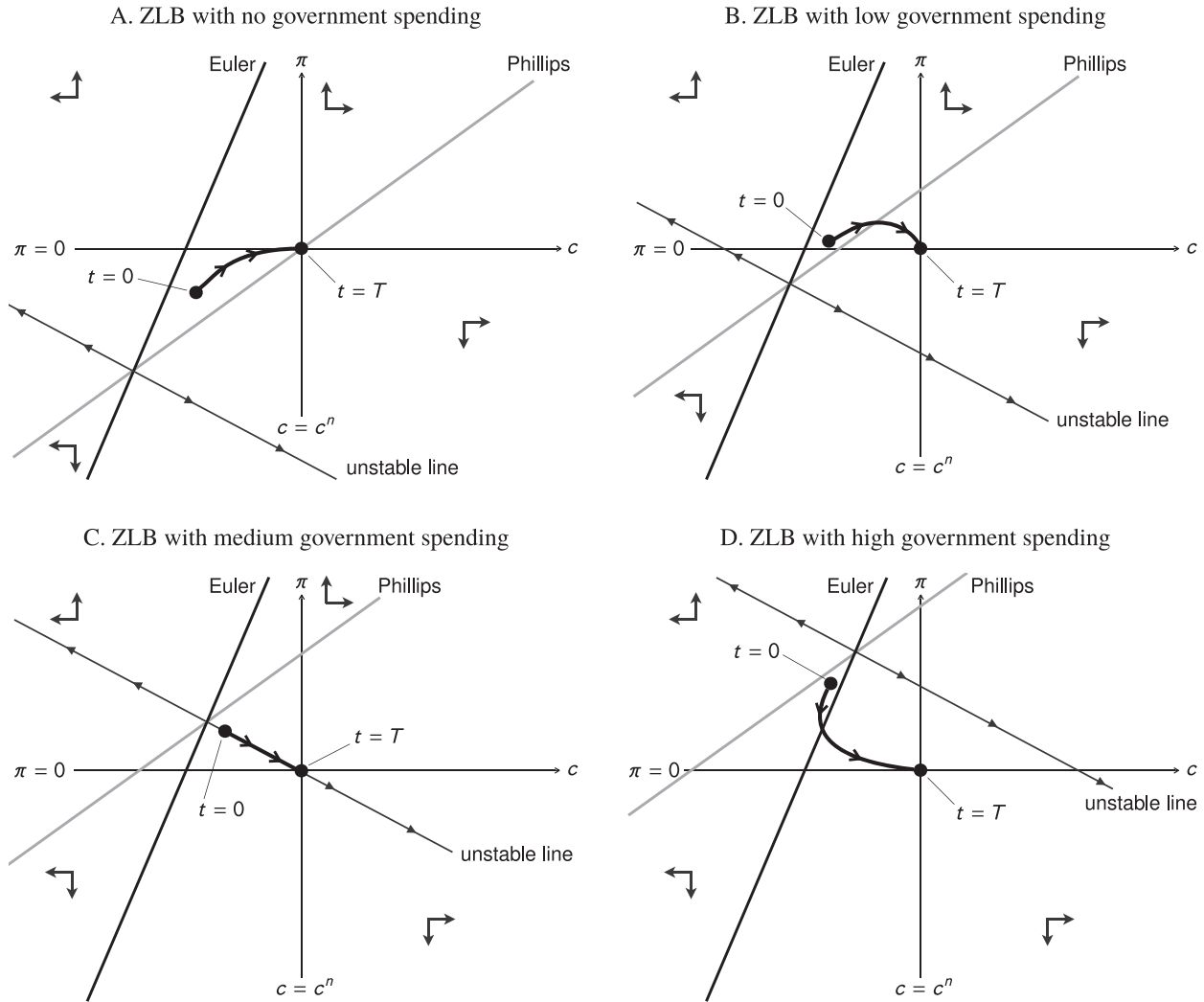
$$m(g, s) = \frac{y(0; g + s/2) - y(0; g - s/2)}{s} \\ = 1 + \frac{c(0; g + s/2) - c(0; g - s/2)}{s}$$

be the government-spending multiplier.

- In the NK model, there exists a government spending g^* such that the government-spending multiplier becomes infinitely large when the ZLB duration approaches infinity: for any $s > 0$, $\lim_{T \rightarrow \infty} m(g^*, s) = +\infty$. In addition, when government spending is above g^* , a long-enough ZLB episode generates an arbitrarily large boom: for any $g > g^*$, $\lim_{T \rightarrow \infty} c(0; g) = +\infty$.
- In the WUNK model, in contrast, the multiplier has a finite limit when the ZLB duration approaches infinity: for any g and s , when $T \rightarrow \infty$, $m(g, s)$ converges to

$$1 + \frac{\eta}{\frac{u'(0)\delta\gamma a}{\epsilon\kappa} \cdot \frac{\epsilon}{\epsilon-1} \eta^{1/(1+\eta)} - (1+\eta)}. \quad (13)$$

FIGURE 6.—WUNK MODEL: ZLB EPISODES WITH GOVERNMENT SPENDING



The timeline of ZLB episodes with government spending is presented in table 1C. The figure displays the phase diagrams of the linearized Euler-Phillips system for the WUNK model with government spending and convex disutility of labor at the ZLB: c is private consumption; π is inflation; c^n is the natural level of private consumption; the Euler line is the locus $\dot{c} = 0$; the Phillips line is the locus $\dot{\pi} = 0$. The phase diagrams have the same properties as that in figure 1D, except that the Phillips line shifts upward when government spending increases (see equation (11)). The equilibrium trajectory at the ZLB is the unique trajectory reaching the natural steady state at time T . The figure shows that the NK model's anomaly disappears in the WUNK model: the government-spending multiplier is finite when the ZLB becomes arbitrarily long-lasting, and equilibrium trajectories are bounded irrespective of the duration of the ZLB.

Moreover, the economy is bounded above for any ZLB duration: let c^s be private consumption in the ZLB steady state with government spending g ; for any T and for all $t \in (0, T)$, $c(t; g) < \max(c^s, c^n)$.

The anomaly that a finite amount of government spending may generate an infinitely large boom as the ZLB becomes arbitrarily long-lasting is reminiscent of the findings by Christiano, Eichenbaum, and Rebelo (2011, fig. 2), Woodford (2011, fig. 2), and Cochrane (2017, fig. 5). They find that in the NK model, government spending is exceedingly powerful when the ZLB is long-lasting.

In the WUNK model, this anomaly vanishes. Diba and Loisel (2019) and Acharya and Dogra (2019) also obtain more realistic effects of government spending at the ZLB. In addition, Bredemeier, Juessen, and Schabert (2018) obtain

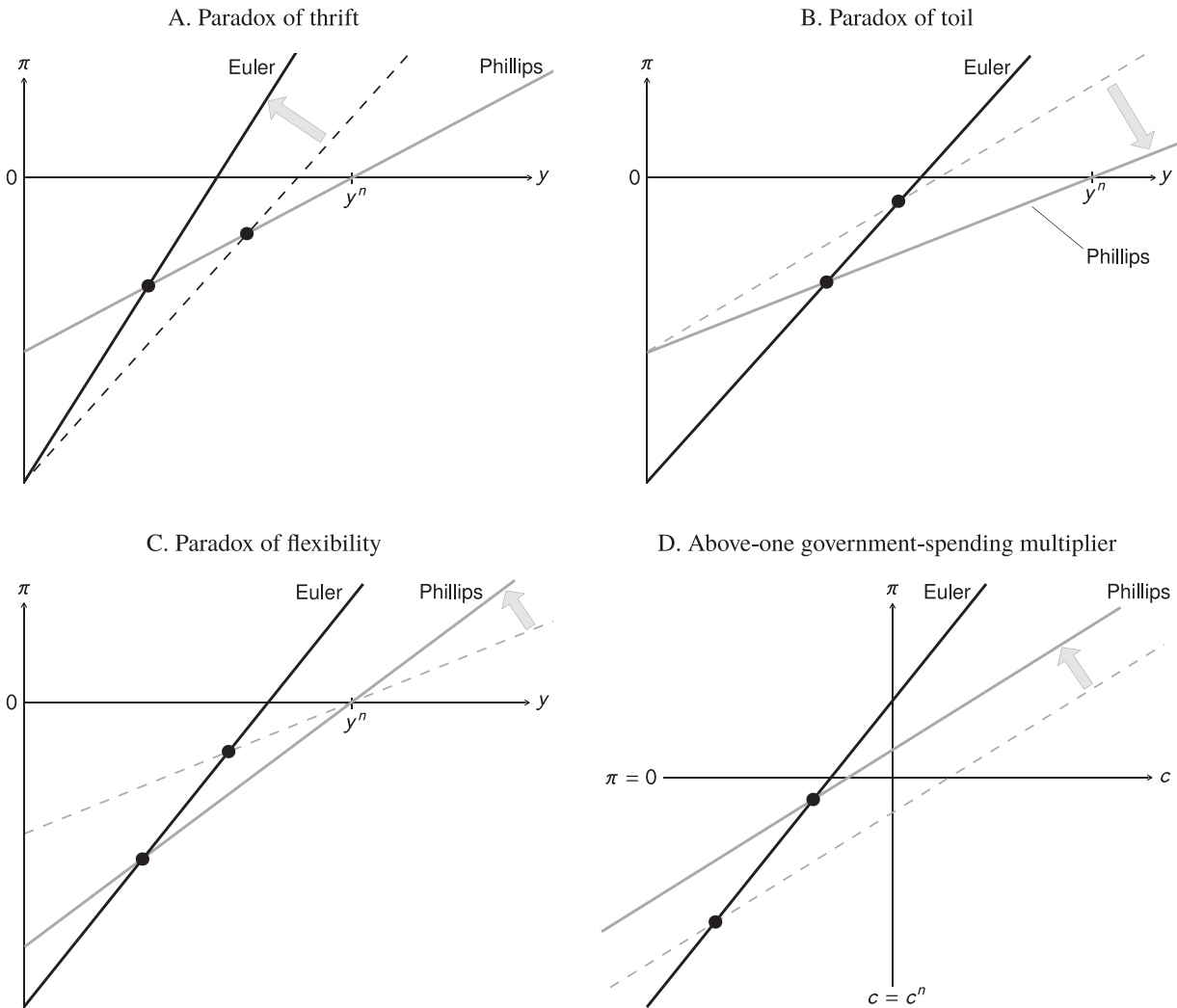
moderate multipliers at the ZLB by introducing an endogenous liquidity premium in the New Keynesian model.

V. Other New Keynesian Properties at the ZLB

Beside the anomalous properties described in section IV, the New Keynesian model has several other intriguing properties at the ZLB: the paradoxes of thrift, toil, and flexibility and a government-spending multiplier greater than 1. We now show that the WUNK model shares these properties.

In the NK model these properties are studied in the context of a temporary ZLB episode. An advantage of the WUNK model is that we can simply work with a permanent ZLB episode. We assume that the natural rate of interest is permanently negative and the central bank keeps the policy rate at 0 forever. The only equilibrium is at the ZLB steady state,

FIGURE 7.—WUNK MODEL: OTHER PROPERTIES AT THE ZLB



The figure displays comparative-static results. The Euler and Phillips lines come from figure 1D (A–C) and from figure 6 (D). The ZLB equilibrium is at the intersection of the Euler and Phillips lines; output/consumption is below its natural level and inflation is negative. (A) Increasing the marginal utility of wealth steepens the Euler line, which depresses output and inflation without changing relative wealth. (B) Reducing the disutility of labor moves the Phillips line outward, which depresses output and inflation. (C) Decreasing the price-adjustment cost rotates the Phillips line counterclockwise around the natural steady state, which depresses output and inflation. (D) Increasing government spending shifts the Phillips line upward, which raises private consumption and therefore increases output more than one-for-one.

where the economy is in a slump: inflation is negative and output is below its natural level. The ZLB equilibrium is represented in figure 7: it is the intersection of a Phillips line, describing the steady-state Phillips curve, and a Euler line, describing the steady-state Euler equation. When an unexpected and permanent shock occurs, the economy jumps to a new ZLB steady state; we use the graphs to study such jumps.

A. Paradox of Thrift

We first study an increase in the marginal utility of wealth ($u'(0)$). The steady-state Phillips curve is unaffected, but the steady-state Euler equation changes. Using equation (5), we rewrite the steady-state Euler equation, given by equation (10):

$$\pi = -\delta + \sigma + u'(0)y.$$

Increasing the marginal utility of wealth steepens the Euler line, which moves the economy inward along the Phillips line. Output and inflation therefore decrease (figure 7A). The following proposition gives the results:

Proposition 6. *At the ZLB in the WUNK model, the paradox of thrift holds: an unexpected and permanent increase in the marginal utility of wealth reduces output and inflation but does not affect relative wealth.*

The paradox of thrift was first discussed by Keynes, but it also appears in the New Keynesian model (Eggertsson, 2010, 16; Eggertsson & Krugman, 2012, 1486). When the marginal utility of wealth is higher, people want to increase their wealth holdings relative to their peers, so they favor saving over consumption. But in equilibrium, relative wealth is fixed at 0 because everybody is the same; the only way to increase saving relative to consumption is to

reduce consumption. In normal times, the central bank would offset this drop in aggregate demand by reducing nominal interest rates. This is not an option at the ZLB, so output falls.

B. Paradox of Toil

Next we consider a reduction in the disutility of labor (κ). In this case, the steady-state Phillips curve changes while the steady-state Euler equation does not. Using equation (2), we rewrite the steady-state Phillips curve, given by equation (3):

$$\pi = \frac{\epsilon\kappa}{\delta\gamma a}y - \frac{\epsilon - 1}{\delta\gamma}.$$

Reducing the disutility of labor flattens the Phillips line, which moves the economy inward along the Euler line. Thus, both output and inflation decrease (figure 7B). Since hours worked and output are related by $h = y/a$, hours fall as well. The following proposition states the results:

Proposition 7. *At the ZLB in the WUNK model, the paradox of toil holds: an unexpected and permanent reduction in the disutility of labor reduces output, inflation, and hours worked.*

The paradox of toil was discovered by Eggertsson (2010, 15) and Eggertsson and Krugman (2012, 1487). It operates as follows. With lower disutility of labor, real marginal costs are lower, and the natural level of output is higher: producers would like to sell more. To increase sales, they reduce their prices by reducing inflation. At the ZLB, nominal interest rates are fixed, so the decrease in inflation raises real interest rates—which renders households more prone to save. In equilibrium, this lowers output and hours worked.¹³

C. Paradox of Flexibility

We then examine a decrease in the price-adjustment cost (γ). The steady-state Euler equation is not affected, but the steady-state Phillips curve is. Equation (3) shows that decreasing the price-adjustment cost leads to a counterclockwise rotation of the Phillips line around the natural steady state. This moves the economy downward along the Euler line, so output and inflation decrease (figure 7C). The following proposition records the results:

Proposition 8. *At the ZLB in the WUNK model, the paradox of flexibility holds: an unexpected and permanent decrease in price-adjustment cost reduces output and inflation.*

The paradox of flexibility was discovered by Werning (2011, 13–14) and Eggertsson and Krugman (2012, 1487–1488). Intuitively, with a lower price-adjustment cost, producers are eager to adjust their prices to bring production closer to the natural level of output. Since production is below the natural level at the ZLB, producers are eager to reduce

their prices to stimulate sales. This accentuates the existing deflation, which translates into higher real interest rates. As a result, households are more prone to save, which in equilibrium depresses output.

D. Above-One Government-Spending Multiplier

We finally look at an increase in government spending (g), using the model with government spending introduced in section IVC. From equation (11) we see that increasing government spending shifts the Phillips line upward, which moves the economy upward along the Euler line: both private consumption and inflation increase (figure 7D). Since private consumption increases when public consumption does, the government-spending multiplier $dy/dg = 1 + dc/dg$ is greater than one. The ensuing proposition gives the results (proof details in online appendix F):

Proposition 9. *At the ZLB in the WUNK model, an unexpected and permanent increase in government spending raises private consumption and inflation. Hence the government-spending multiplier dy/dg is above one; its value is given by equation (13).*

Christiano, Eichenbaum, and Rebelo (2011), Eggertsson (2011), and Woodford (2011) also show that at the ZLB in the New Keynesian model, the government-spending multiplier is above 1. The intuition is the following. With higher government spending, real marginal costs are higher for a given level of sales to households. Producers pass the cost increase through into prices, which raises inflation. At the ZLB, the increase in inflation lowers real interest rates—as nominal interest rates are fixed—which deters households from saving. In equilibrium, this leads to higher private consumption and a multiplier above one.

VI. Empirical Assessment of the WUNK Assumption

In the WUNK model, the marginal utility of wealth is assumed to be high enough that the steady-state Euler equation is steeper than the steady-state Phillips curve at the ZLB. We assess this assumption using US evidence.

As a first step, we reexpress the WUNK assumption in terms of estimable statistics. We obtain the following condition (derivations in online appendix G):

$$\delta - r^n > \frac{\lambda}{\delta}, \quad (14)$$

where δ is the time discount rate, r^n is the average natural rate of interest, and λ is the coefficient on output gap in a New Keynesian Phillips curve. The term $\delta - r^n$ measures the marginal rate of substitution between wealth and consumption, $u'(0)y^n$. It indicates how high the marginal utility of wealth is and thus how steep the steady-state Euler equation is at the ZLB. The term λ/δ indicates how steep the steady-state Phillips curve is. The δ comes from the denominator

¹³An increase in technology (a) would have the same effect as a reduction in the disutility of labor: it would lower output, inflation, and hours.

of the slopes of the Phillips curves, given by equations (3) and (11); the λ measures the rest of the slope coefficients. Condition (14) is expressed in terms of sufficient statistics, so it applies when the disutility of labor is linear (in which case it is equivalent to condition (9)) and when the disutility of labor is convex (in which case it is equivalent to condition (12)). We now survey the literature to obtain estimates of r^n , λ , and δ .

A. Natural Rate of Interest

A large number of macroeconomic studies have estimated the natural rate of interest, using different statistical models, methodologies, and data. Recent studies obtain comparable estimates of the natural rate for the United States: around 2% per annum on average between 1985 and 2015 (Williams, 2017, fig. 1). Accordingly, we use $r^n = 2\%$ as our estimate.

B. Output-Gap Coefficient in the New Keynesian Phillips Curve

Many studies have estimated New Keynesian Phillips curves. Mavroeidis, Plagborg-Moller, and Stock (2014, sec. 5) offer a synthesis for the United States. They generate estimates of the New Keynesian Phillips curve using an array of US data, methods, and specifications found in the literature. They find significant uncertainty around the estimates, but in many cases, the output-gap coefficient is positive and very small. Overall, their median estimate of the output-gap coefficient is $\lambda = 0.004$ (table 5, row 1), which we use as our estimate.

C. Time Discount Rate

Since the 1970s, many studies have estimated time discount rates using field and laboratory experiments and real-world behavior. Frederick, Loewenstein, and O'Donoghue (2002, table 1) survey 43 such studies. The estimates are quite dispersed, but the majority of them point to high discount rates, much higher than prevailing market interest rates. We compute the mean estimate in each of the studies covered by the survey and then compute the median value of these means. We obtain an annual discount rate of $\delta = 35\%$.

There is one immediate limitation with the studies discussed by Frederick, Loewenstein, and O'Donoghue: they use a single rate to exponentially discount future utility. But exponential discounting does not describe reality well because people seem to choose more impatiently for the present than for the future—they exhibit present-focused preferences (Ericson & Laibson, 2019). Recent studies have moved away from exponential discounting and allowed for present-focused preferences, including quasi-hyperbolic (β - δ) discounting. Andersen et al. (2014, table 3) survey 16 such studies, concentrating on experimental studies with real incentives. We compute the mean estimate in each study and

then the median value of these means; we obtain an annual discount rate of $\delta = 43\%$. Accordingly, even after accounting for present focus, time discounting remains high. We use $\delta = 43\%$ as our estimate.¹⁴

D. Assessment

We now combine our estimates of r^n , λ , and δ to assess the WUNK assumption. Since λ is estimated using the quarter as the unit of time, we reexpress r^n and δ as quarterly rates: $r^n = 2\%/4 = 0.5\%$ per quarter, and $\delta = 43\%/4 = 10.8\%$ per quarter. We conclude that condition (14) comfortably holds: $\delta - r^n = 0.108 - 0.005 = 0.103$, which is much larger than $\lambda/\delta = 0.004/0.108 = 0.037$. Hence, the WUNK assumption holds in US data.

The discount rate used here (43% per annum) is much higher than discount rates used in macroeconomic models (typically less than 5% per annum). This is because our discount rate is calibrated from microevidence, while the discount rate in macroeconomic models is calibrated to match observed real interest rates.

This discrepancy occasions two remarks. First, the wealth-in-the-utility assumption is advantageous because it accords with the fact that people exhibit double-digit discount rates and yet are willing to save at single-digit interest rates. In the standard model, by contrast, the discount rate equals the real interest rate in steady state, so the model cannot accommodate double-digit discount rates.

Second, the WUNK assumption would also be satisfied with annual discount rates below 43%. Indeed, condition (14) holds for discount rates as low as 27% because $\delta - r^n = (0.27/4) - 0.005 = 0.062$ is greater than $\lambda/\delta = 0.004/(0.27/4) = 0.059$. An annual discount rate of 27% is at the low end of available microestimates: in 11 of the 16 studies in Andersen et al. (2014, table 3), the bottom of the estimate range is above 27%, and in 13 of the 16 studies, the mean estimate is above 27%.

¹⁴There are two potential issues with the experiments discussed in Andersen et al. (2014). First, many are run with university students instead of subjects representative of the general population. There do not seem to be systematic differences in discounting between student and nonstudent subjects, however (Cohen et al., 2020, 334). Hence, using students is unlikely to bias the estimates reported by Andersen et al. Second, all the experiments elicit discount rates using financial flows, not consumption flows. As the goal is to elicit the discount rate on consumption, this could be problematic; the problems could be exacerbated if subjects derive utility from wealth. To assess this potential issue, suppose first (as in most of the literature) that monetary payments are consumed at the time of receipt and that the utility function is locally linear. Then the experiments deliver estimates of the relevant discount rate (Cohen et al., 2020, 323–325). If these conditions do not hold, the experimental findings are more difficult to interpret. For instance, if subjects optimally smooth their consumption over time by borrowing and saving, then the experiments only elicit the interest rate faced by subjects and reveal nothing about their discount rate (Cohen et al., 2020, 322–323). In that case, we should rely on experiments using time-dated consumption rewards instead of monetary rewards. Such experiments directly deliver estimates of the discount rate. Many such experiments have been conducted; a robust finding is that discount rates are higher for consumption rewards than for monetary rewards (Cohen et al., 2020, 312–315). Hence, the estimates presented in Andersen et al. are, if anything, lower bounds on actual discount rates.

Finally, while our model omits firms and assumes that households are both producers and consumers, in reality firms and households are often separate entities that could have different discount rates. With different discount rates, condition (14) would become

$$\delta^h - r^n > \frac{\lambda}{\delta^f},$$

where δ^h is households' discount rate and δ^f is firms' discount rate. Clearly, if firms have a low discount rate, the WUNK assumption is less likely to be satisfied. If we use $\delta^h = 43\%$, $r^n = 2\%$, and $\lambda = 0.004$, the condition holds as long as firms have an annual discount rate above 16% because $\delta^h - r^n = (0.43/4) - 0.005 = 0.103$ is greater than $\lambda/\delta^f = 0.004/(0.16/4) = 0.100$. A discount rate of 16% is only slightly above that reported by large US firms: in a survey of 228 CEOs, Poterba and Summers (1995) find an average annual real discount rate of 12.2%, and in a survey of 86 CFOs, Jagannathan et al. (2016, 447) find an average annual real discount rate of 12.7%.

VII. Conclusion

This paper proposes an extension of the New Keynesian model that is immune to the anomalies that plague the standard model at the ZLB. The extended model deviates only minimally from the standard model: relative wealth enters the utility function, which adds an extra term only in the Euler equation. Yet when the marginal utility of wealth is sufficiently high, the model behaves well at the ZLB: even when the ZLB is long-lasting, there is no collapse of inflation and output, and both forward guidance and government spending have limited, plausible effects. The extended model also retains other properties of the standard model at the ZLB: the paradoxes of thrift, toil, and flexibility and a government-spending multiplier greater than 1.

Our analysis would apply more generally to any New Keynesian model representable by a discounted Euler equation and a Phillips curve (Del Negro, Giannoni, & Patterson, 2015; Gabaix, 2016; McKay, Nakamura, & Steinsson, 2017; Campbell et al., 2017; Beaudry & Portier, 2018; Angeletos & Lian, 2018). Wealth in the utility function is a simple way to generate discounting; but any model with discounting would have similar phase diagrams and properties. Hence, for such models to behave well at the ZLB, there is only one requirement: that discounting is strong enough to make the steady-state Euler equation steeper than the steady-state Phillips curve at the ZLB; the source of discounting is unimportant. In the real world, several discounting mechanisms might operate at the same time and reinforce each other. A model blending these mechanisms would be even more likely to behave well at the ZLB.

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