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Fear of Liftoff: Uncertainty, Rules, and Discretion in Monetary Policy Normalization

Athanasios Orphanides

As the author describes it, the Federal Reserve's muddled mandate to attain simultaneously the incompatible goals of maximum employment and price stability invites short-term-oriented discretionary policymaking inconsistent with the systematic approach needed for monetary policy to contribute best to the economy over time. Fear of liftoff—the reluctance to start the process of policy normalization after the end of a recession—serves as an example. Drawing on public choice and cognitive psychology perspectives, the author discusses causes of this problem: The Federal Reserve could adopt a framework that relies on a simple policy rule subject to periodic reviews and adaptation. Replacing meeting-by-meeting discretion with a simple policy rule would eschew discretion in favor of systematic policy. Periodic review of the rule would allow the Federal Reserve the flexibility to account for and occasionally adapt to the evolving understanding of the economy. Congressional legislation could guide the Federal Reserve in this direction. However, the Federal Reserve may be best placed to select the simple rule and could embrace this improvement on its own, within its current mandate, with the publication of a simple rule along the lines of its statement of longer-run goals. (JEL E32, E52, E58, E61)

Federal Reserve Bank of St. Louis *Review*, Third Quarter 2015, 97(3), pp. 173-96.

The Federal Reserve has faced unprecedented challenges since the onset of the most recent recession in December 2007. The downturn was exacerbated by the most severe financial crisis since the Great Depression and prompted an unprecedented policy response. By the time the recession ended in June 2009, it had become the longest in post-World War II history. Monetary policy has remained unprecedented since then. Massive monetary policy accommodation in the form of quantitative easing (QE) was engineered by the Federal Reserve long after the end of the recession; and, even today—six years after the end of the recession—the Federal Reserve has yet to begin the process of normalization. Does the observed delay in normalizing policy suggest a break with the past? Does it lend

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support to broader concerns about the monetary policy strategy of the Federal Reserve and calls for changing the legal framework governing the institution?¹ What are the risks associated with fear of liftoff?

Using the current environment as a springboard, the goal of this article is to put the Federal Reserve's policy problem in a historical perspective and assess institutional safeguards that can ensure that monetary policy contributes in the best possible manner to economic prosperity in our democratic society. Themes discussed along the way would be recognized as hardy perennials: How systematic, transparent, and predictable should monetary policy be? What are the practical challenges faced in an uncertain and constantly evolving macroeconomic landscape? How much discretion should be encouraged or tolerated to deliver reasonably good outcomes in practice?²

In the United States and elsewhere, the central bank has been granted considerable independence to encourage systematic monetary policy and protect the policy process from politics and other factors that invite populist "short-termist" behavior—behavior that favors immediate gratification at a long-term loss to society. But central bank independence may be insufficient to achieve good results when policy is set in a discretionary fashion, especially when the central bank is overburdened with numerous and potentially incompatible objectives.

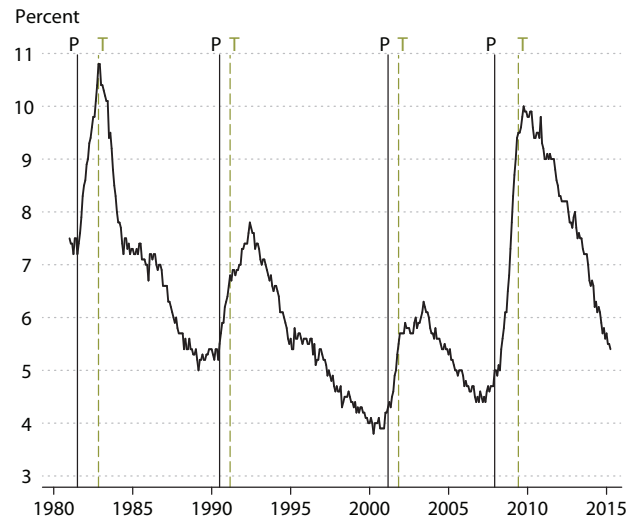
The historical record of Federal Reserve policymaking is decidedly mixed. In its first hundred years, the Federal Reserve experienced ups and downs, with periods of good, bad, and terrible policy. For a number of years before the latest recession, policy compared well with the past. Policy since the end of the latest recession, however, has raised concerns. Policy liftoff has been debated, on and off, for at least five years. While the depth of the recession justified a delay in the early stages of the recovery, the Federal Reserve's continuing reluctance to start the policy normalization process suggests a deviation from the earlier norm. Placing recent policy decisions in a historical context and evaluating the causes for this apparent deviation provides guidance on how the institutional environment governing monetary policy in the United States can be improved.

FOUR RECESSIONS

A comparison of the unemployment, inflation, and interest rates over the past four business cycles is a useful starting point to put the most recent recession in historical perspective. Focusing on the three recessions before the most recent provides a useful benchmark as this period spans what has become known as the Great Moderation, a period generally associated with greater success in the formulation of monetary policy than the period preceding it.³

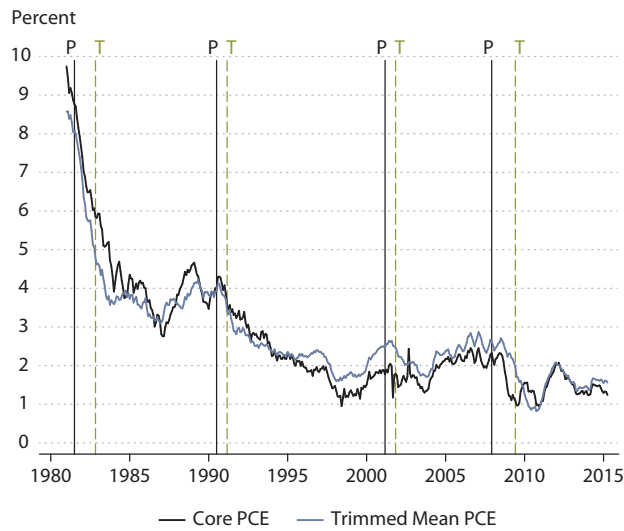
Figure 1 shows the evolution of the unemployment rate in the United States over the past four business cycles.⁴ Vertical lines denote peaks and troughs of recessions as determined by the National Bureau of Economic Research (NBER) Business Cycle Dating Committee. A distinguishing characteristic of recessions is that the unemployment rate rises sharply during the downturn, peaks at or soon after the trough, and subsequently declines for a number of years. The latest recession was associated with a very large increase in the unemployment rate and has been called the Great Recession. Note, however, that the unemployment rate did not

Figure 1
Four Recessions: Unemployment



NOTE: The vertical lines denote business cycle peaks (P) and troughs (T).
 SOURCE: FRED®, Federal Reserve Economic Data, Federal Reserve Bank of St. Louis; and NBER for business cycle dates.

Figure 2
Four Recessions: Inflation



NOTE: The vertical lines denote business cycle peaks (P) and troughs (T). PCE, personal consumption expenditures.
 SOURCE: FRED®, Federal Reserve Economic Data, Federal Reserve Bank of St. Louis for core PCE; and Federal Reserve Bank of Dallas for trimmed mean PCE.

Figure 3

Four Recessions: Real Interest Rate

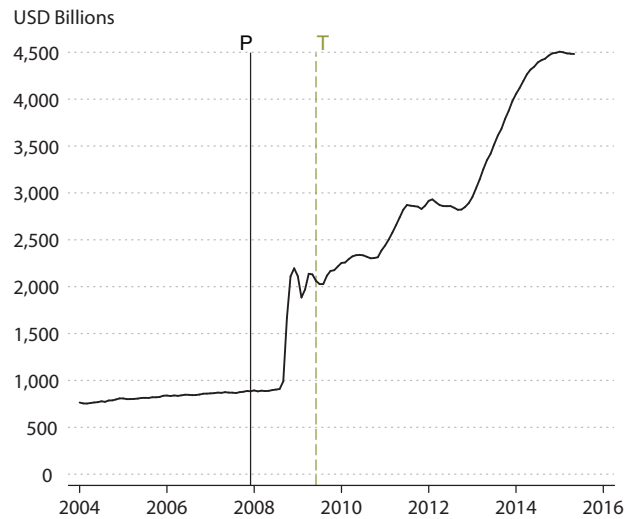


NOTE: The real interest rate reflects the difference between the 12-month T-bill rate and the year-ahead inflation expectations rate. The vertical lines denote business cycle peaks (P) and troughs (T).

SOURCE: FRED®, Federal Reserve Economic Data, Federal Reserve Bank of St. Louis for T-bill data; Federal Reserve Bank of Philadelphia for inflation expectations; and author's calculations.

Figure 4

Additional Policy Accommodation through QE



NOTE: The figure shows the size of the Federal Reserve balance sheet. The vertical lines denote business cycle peaks (P) and troughs (T).

SOURCE: FRED®, Federal Reserve Economic Data, Federal Reserve Bank of St. Louis.

reach the peak it had reached during 1982. Arguably, the 1981-82 recession was more painful than the most recent episode even though it did not earn the moniker the Great Recession.

Figure 2 shows the corresponding history of inflation. The figure plots core and trimmed mean inflation measures to avoid the distraction of fluctuations driven by highly volatile components. As the figure shows, overall, inflation was relatively stable over the past three business cycles, in contrast to the experience during the 1981-82 recession. Indeed, the high inflation episode that ended with the 1981-82 recession is one reason the high unemployment rate during 1982 is not judged as negatively as the high unemployment rate in the most recent recession. The high unemployment rate tolerated during the 1981-82 recession could be viewed as the price the country had to pay to correct for earlier excesses that gave rise to the malaise of high inflation.

The evolution of real interest rates highlights the response of monetary policy across these four recessions. One proxy, shown in Figure 3, can be constructed as the difference between the 12-month Treasury bill rate and the year-ahead inflation expectations reflected in the Survey of Professional Forecasters (SPF). The current episode had the most massive policy accommodation that can be seen in this sample. For the past five years, the Federal Reserve has engineered a very negative short-term real interest rate—much more negative than during the previous two recessions, when inflation was similar to the current episode. A much higher real interest rate was tolerated during and after the 1981-82 recession, but that episode is not comparable, as the tight policy was needed to tame inflation.

In addition to the massive policy accommodation engineered during the latest recession as seen in the real interest rate, another exceptional feature is the large expansion of the Federal Reserve balance sheet (Figure 4). With policy rates close to zero—as they have been since late 2008—an expansion of the balance sheet provides additional monetary policy accommodation, beyond what is associated with the reduction in the short-term real interest rate.⁵ What is remarkable in this episode is how much additional policy accommodation was provided long after the recession ended in June 2009. As the figure shows, the QE policy in 2011 (QE2) and even more so the open-ended QE policy that started in September 2012 (QE3) and ended only in October 2014, led to a doubling of the size of the Federal Reserve balance sheet compared with its level at the end of the recession.

EXTRAORDINARY POLICY ACCOMMODATION AFTER THE LATEST RECESSION

The policy easing associated with the latest recession, as compared with past experience, raises a number of questions. Two pertinent questions are why the Federal Reserve has engineered this extraordinary degree of policy accommodation so long after the end of the recession and why the Federal Reserve has not yet taken any steps toward beginning the process of normalizing policy.

One answer can be found in the rationale that apparently served to justify the policy. Characteristic is the hint provided in a speech by Ben Bernanke at the last Jackson Hole Symposium he attended as Federal Reserve Chairman. The speech was delivered on August 31,

2012, and effectively telegraphed the QE3 policy that started two weeks later. Bernanke (2012) argued that (i) the recovery from the recession until then was weaker than had been anticipated and (ii) the unemployment rate remained higher than hoped. Suggesting that more improvement could be sought, he remarked:

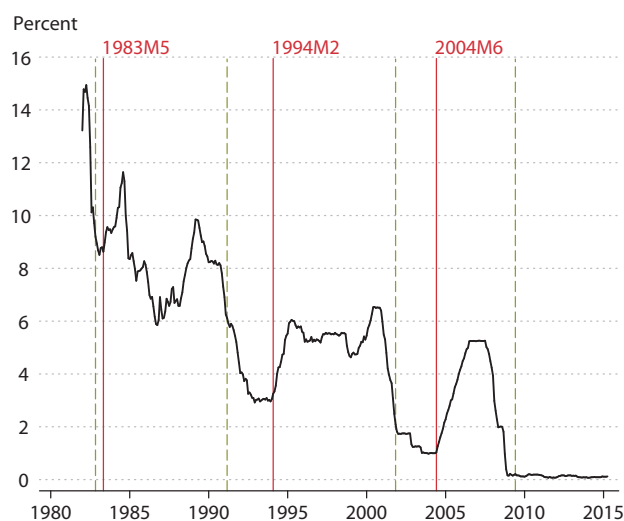
[F]ollowing every previous U.S. recession since World War II, the unemployment rate has returned close to its pre-recession level, and, although the recent recession was unusually deep, I see little evidence of substantial structural change in recent years.

If one were to interpret the Chairman's observation as a guide for policy, which is suggestive, one might have thought that the Federal Reserve had determined that even though three years had already passed since the end of the recession—and despite the unprecedented monetary policy accommodation already in place—additional easing was desirable to push the unemployment rate lower and about in line with the low level in the pre-recession mid-2000s. What Chairman Bernanke did not clarify at the time, however, was whether pushing so hard to lower the unemployment rate after recessions had always proven to be good policy for the Federal Reserve. Experience suggests otherwise. Recalling the post-World War II experience of the United States, we know that a strategy of easing policy aiming at pushing the unemployment rate down has not always been a happy experience for the Federal Reserve. During the 1960s and 1970s, activist policies with excessive emphasis on reducing the unemployment rate after recessions not only did not deliver good macroeconomic outcomes but, on the contrary, added to instability in the economy.⁶

As already mentioned, the unemployment rate tends to rise quickly during recessions. It also tends to be a lagging indicator and may increase somewhat further after the end of a recession. In the most recent episode, for example, the recession ended in June 2009 while the unemployment rate peaked at 10 percent in October 2009. After a recession ends, as the economy improves and with the monetary accommodation engineered in response to the recession still in place, the unemployment rate tends to gradually decline over a period of years. In the case of the latest recession, by August 2012 the unemployment rate had already declined by 2 percentage points from its peak of 8 percent and was expected to decline further. This is the context in which the decision to embark on QE3 in September 2012 was made. The zeal with which the Federal Reserve pursued monetary policy accommodation to reduce unemployment following the Great Recession appeared to resemble the mentality of monetary policy before rather than during the Great Moderation era.

THE CASE OF THE MISSING LIFTOFF

What is the pattern of monetary policy after recessions end? When does the policy-easing cycle end and the process of normalization begin? As shown in Figure 5, which plots the federal funds rate, a pattern of continued policy easing for some time after the end of a recession is not uncommon. In the current episode, with the federal funds rate close to zero by the end of the recession, the QE policy described earlier served this role. Subsequently, as the economy improves, the process of unwinding this process commences. This is when policy liftoff is observed.

Figure 5**Federal Funds Rate and Liftoff**

NOTE: The green vertical lines denote business cycle troughs. The red vertical lines denote the month of liftoff following business cycle troughs.

SOURCE: FRED®, Federal Reserve Economic Data, Federal Reserve Bank of St. Louis.

Table 1**Policy Liftoff After the End of Four Recessions**

Recession dates		Policy liftoff	
Peak	Trough	Liftoff month	Months after trough
July 1981	November 1982	May 1983	7
July 1990	March 1991	February 1994	35
March 2001	November 2001	June 2004	32
December 2007	June 2009	?	72+

Liftoff occurred on May 1983, February 1994, and June 2004 for the first three recessions (shown by the red lines in Figure 5); the liftoff dates ranged from within a year to within three years from the end of a recession. (The recession and liftoff dates are summarized in Table 1.) By contrast, in the latest episode, six years after the end of the recession liftoff has yet to be observed. And this is despite the massive policy accommodation—much greater than in the previous three business cycles—that will need to be unwound to normalize policy.

What is the cause of this delay? One consideration is that the date of liftoff should depend on the state of the economy, in particular the assessment of how far the recovery has progressed from the end of the recession. As suggested in the remark by Ben Bernanke that was quoted

Figure 6**Unemployment and Liftoff**

NOTE: The green vertical lines denote business cycle troughs. The red vertical lines denote the month of liftoff following business cycle troughs.

SOURCE: FRED®, Federal Reserve Economic Data, Federal Reserve Bank of St. Louis.

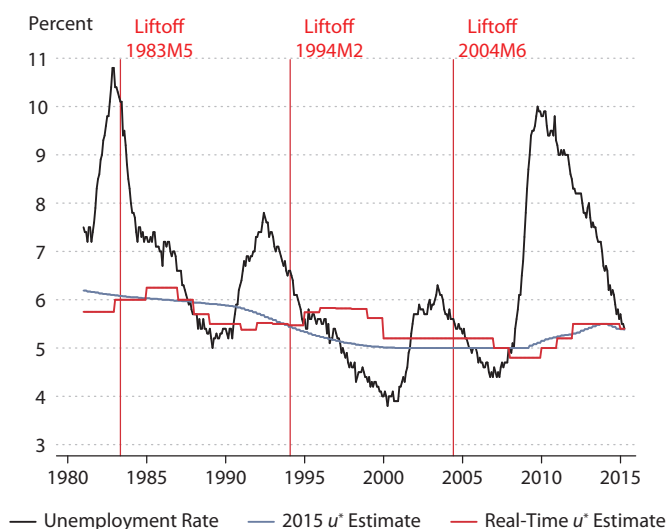
earlier, one indicator is how much progress has been made in restoring the unemployment rate to a low level. To the extent that progress has been slower in the latest episode relative to the earlier recessions, some of the delay may be explained and is not inconsistent with past experience. But there are limits to this argument.

Liftoff is not the end of the phase of improvement in the economy. When monetary policy is appropriately conducted, liftoff does not mark the end of the expansion phase of the business cycle. Figure 6 illustrates this point by reproducing the unemployment rate and adding vertical lines indicating recession troughs and the subsequent policy liftoff dates. Judging from past experience in a period when monetary policy is generally considered to have been successful, the economy continues to improve long after liftoff occurs.

What then might serve as a benchmark for when liftoff is overdue? Perhaps the notion of the natural rate of unemployment could serve this role—that is, the rate of unemployment corresponding to “full employment” in the sense that it is compatible with price stability over the long run. Indeed, numerous policymakers have referred to estimates of full employment and the natural rate of unemployment as informing their thinking about policy.⁷ One complication is that the natural rate of unemployment is not observed and estimates are highly uncertain and subject to revision, a reason not all policymakers consider the concept particularly useful for policy deliberations. Still, it is instructive to examine the historical experience of liftoff in relation to the progress made by the economy following a recession relative to reasonable estimates of the natural rate of unemployment.

Figure 7

Full Employment Estimates and Liftoff



NOTE: Estimates of the natural rate of unemployment (u^*) as published by the CBO. The 2015 estimates are from January 2015. Real-time estimates show in each year the CBO estimate published during that year.

SOURCE: FRED®, Federal Reserve Economic Data, Federal Reserve Bank of St. Louis for the unemployment rate; CBO for u^* .

Table 2

Unemployment Rate and Policy Liftoff

Dates		Unemployment rate (%)		
Recession trough	Liftoff month	Actual	Natural (real-time)	Gap
November 1982	May 1983	10.1	6.0	4.1
March 1991	February 1994	6.4	5.5	0.9
November 2001	June 2004	5.6	5.2	0.4
June 2009	?	?	5.4*	?

NOTE: *January 2015 CBO estimate for the natural rate of unemployment for 2015 (5.4 percent).

Figure 7 plots the unemployment rate together with estimates of the natural rate of unemployment (u^*) as published by the Congressional Budget Office (CBO). The CBO estimates are shown because of the availability of a long and consistent history of estimates, which are revised about once a year. The time-series estimate published in January 2015 is shown in blue. Comparison with the unemployment rate time series can give us an indication of the timing of liftoff relative to the most recent estimates of what the natural rate of unemployment was at the time. Since these estimates are revised, however, a more informative comparison for policy-

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making would be with estimates of the natural rate available in real time. The real-time CBO estimates are shown in red.⁸

Figure 7 illustrates that, after past recessions, policy liftoff occurred well ahead of the unemployment rate reaching estimates of the natural rate of unemployment. This holds both when the January 2015 as well as real-time estimates of the natural rate are used. As shown in Table 2, in the 2004 and 1994 episodes, liftoff occurred while the unemployment rate was almost half a percentage point and almost 1 percentage point, respectively, above the estimates of the natural rate of unemployment the CBO had published at that time. In 1983, the gap exceeded 4 percentage points, consistent with the tight policy bias needed to restore price stability.

In contrast, the current episode points to a case of the missing liftoff. The latest available observation for the unemployment rate (for April 2015) coincides with the January 2015 CBO estimate of the natural rate; and, given the additional decline in the unemployment rate expected over the coming months, it appears that liftoff will not have occurred until after the unemployment rate falls below this estimate of the natural rate.

Fear of liftoff represents a significant aberration relative to the successful conduct of monetary policy in recent decades. To understand the adverse consequences of a delay in normalizing policy one needs only to return to the basic principles of policy design. In light of the long and variable transmission lags, monetary policy ought to be preemptive. If policymakers wish to ensure full employment and price stability over time, they cannot afford to permit immense policy accommodation in the system once full employment is reached. If they did, it would not be feasible to withdraw that accommodation on time without either generating inflation or tightening so abruptly it could cause a recession. For this reason, policy normalization ought to commence long before reasonable estimates suggest full employment has been restored.

The Federal Reserve followed this prudent, preemptive approach after every recession in recent decades. This strategy kept inflation in line with reasonable price stability and avoided stop-go cycles and abrupt and costly corrections. Not this time. Six years after the end of the Great Recession, the Federal Reserve has yet to begin the process of normalization from the unprecedented monetary accommodation it engineered during and after the Great Recession.

The apparent delay in liftoff would be less severe than suggested above if the correct measure of full employment corresponds to a natural rate of unemployment that is significantly below the January 2015 CBO estimate. Indeed, we cannot know what the appropriate threshold is. Estimates of the natural rate are highly uncertain and subject to revision. Table 3 presents a list of alternative suggested estimates that have been published recently (on the dates shown). The January 2015 CBO estimate falls within the range of alternative estimates, including those based on responses to survey questions of professional forecasters. The FOMC is also providing indirect readings of participants' views in the Summary of Economic Projections (SEP) that has been published once per quarter in recent years. Specifically, the Committee publishes the range and central tendency of participants' assessments of the unemployment rate expected to prevail in the "longer run." Interestingly, while in December 2014 the central tendency of the implied estimates (5.2-5.5 percent) encompassed the latest reading of the unemployment rate (5.4 percent for April), the most recent central tendency (5.0-5.2 percent) falls somewhat

Table 3**Estimates of the Natural Rate of Unemployment**

Source	Date	Estimate (%)
SPF median	August 2014	5.5
Blue Chip mean	October 2014	5.4
FOMC central tendency	December 2014	5.2-5.5
FOMC range	December 2014	5.0-5.8
CBO	January 2015	5.4
Blue Chip mean	March 2015	5.1
FOMC central tendency	March 2015	5.0-5.2
FOMC range	March 2015	4.9-5.8

below. The range of estimates, which includes all responses, has been notably wider, indicating substantial diversity of views. It changed only slightly from 5.0-5.8 percent in December to 4.9-5.8 percent in March.⁹ For the majority of the Committee, the recent revision could be used to argue that the FOMC's delay in liftoff is not necessarily internally inconsistent with appropriately preemptive policy. But for some members, the unemployment rate has already fallen below the suggested estimate of the natural rate. Overall, the unemployment rate has fallen so much since the end of the recession, relative to most estimates of the natural rate, that liftoff appears to be overdue, judging from the experience of the three earlier recessions.

CAUSES OF FEAR OF LIFTOFF

What explains fear of liftoff? For an answer, it is useful to go back to the basics and recall the mandate of the Federal Reserve and how policy decisions are made.

One problem is the muddled mandate of the Federal Reserve. More precisely, the wording of the mandate is open to interpretations that can potentially create immense problems for policymaking:

The Board of Governors of the Federal Reserve System and the Federal Open Market Committee shall maintain long run growth of the monetary and credit aggregates commensurate with the economy's long run potential to increase production, so as to promote effectively the goals of maximum employment, stable prices, and moderate long-term interest rates. (Federal Reserve Act, Section 2A, 1977 amendment; U.S. Congress, 1977)

In the last sentence, the goals of "maximum employment" and "stable prices" suggest an incoherent mandate. How can the Federal Reserve simultaneously achieve maximum employment and stable prices? Through more accommodative monetary policy, one can always get more employment today if one is willing to risk unstable prices later on. While the Federal Reserve is an independent central bank, which facilitates setting policy in accordance with a clear mandate, it has a muddled mandate that creates ambiguity about what it should be aiming for.

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The muddled mandate invites potentially harmful discretion. It need not cause great harm when the mandate is interpreted in the proper manner, but it can create notable difficulties when it is not.

What creates the risk of bad outcomes? A key issue is the real-time uncertainty and disagreement regarding what constitutes “maximum employment” and its incompatibility with “stable prices.” The temptation to explore the limits of the meaning of maximum employment invites harmful discretion. Discretion could then lead to a short-term focus on what is perceived to be the most salient problem facing policymakers at the time rather than the long-term focus needed to defend social welfare over time. This short-term focus may change depending on economic conditions and circumstances, making policy less systematic over time. Following a painful recession, such as the recent experience, the most salient problem becomes high unemployment. This induces excessive focus on reducing unemployment, creating fear of liftoff after recessions and eventually generating stop-go cycles.

How can we ensure that the policy process within which policymakers operate in practice delivers the best possible decisions? A robust policy framework should account for the difficulties introduced by the Federal Reserve’s flawed mandate and address the potential for harmful discretion.

Even with best intentions, policymakers are human and subject to the same sources of biases all humans face. In the presence of biases, proper rules and guidance are needed to make policy decisions that systematically deliver good outcomes over time. Can discretionary policy achieve the “optimal” performance corresponding to an infinite-horizon optimization problem under uncertainty, accurately reflecting social welfare, as is often assumed in theoretical treatments of the monetary policy problem? I do not believe so. Humans are not wired to make decisions in this manner. To explore the implications of this difficulty, we could benefit from a brief look at alternative perspectives, such as a public choice or a cognitive psychology perspective to the policy problem.

THE PUBLIC CHOICE PERSPECTIVE

The public choice perspective acknowledges the presence of a principal-agent relationship between society and appointed policymakers. Personal objectives of appointed policymakers may not coincide with social objectives. In the context of monetary policy, a question that arises is this: What institutional framework can ensure that policymakers’ incentives induce decisions consistent with delivering good outcomes from society’s perspective? The problem is well known but traditional treatments of the monetary policy problem tend to ignore this complication. Its relevance can be illustrated by referring to a comment by Milton Friedman on the well-known survey by Stanley Fischer (1990) on “Rules versus Discretion in Monetary Policy.” In his survey, Fischer discussed the problems associated with discretionary monetary policy and the advantages of well-designed policy rules in solving the problem of dynamic inconsistency but maintained, as an assumption, the idea that policymakers aimed to achieve price stability and full employment. This prompted the following comment by Friedman, which Fischer reproduced in footnote 52 in the concluding section of his paper:

The major comment is the omission of what I have increasingly come to regard as Hamlet on this issue [rules versus discretion], namely the public choice perspective. To illustrate... you talk about a loss function for “the policymaker” that includes solely inflation and the deviation of real output from a target level. If we bring this down to earth, these are likely to be only very indirectly related to the real objectives of the actual policymakers. From revealed preference, I suspect that by far and away the two most important variables in their loss function are avoiding accountability on the one hand and achieving public prestige on the other. A loss function that contains those two elements as its main argument will I believe come far closer to rationalizing the behavior of the Federal Reserve over the past 73 years than one such as you have used. (Quoted in Fischer, 1990, p. 1181)

To be sure, Friedman’s claim that “avoiding accountability” and “achieving public prestige” may be a more accurate description of the personal goals of actual policymakers than the economic objectives typically associated with central bank mandates may appear extreme. Indeed, judging from my personal observation of the global central banking community, I would argue that, overall, in the case of the Federal Reserve, this is not a good characterization. On the other hand, Friedman’s description of how actual policymakers operate rings true with a frequency that is not insignificant in other parts of the world, and it cannot be excluded outright as a possible future issue for the Federal Reserve. Success in this regard is sensitive to maintaining an effective appointment process, drawing on tradition, a high degree of professionalism, and the reputation of the institution, something that might be compromised even in an otherwise well-functioning democracy. Around the world, unfortunately, examples of failure are not uncommon.

Needless to say, to the extent Friedman’s description holds true, even partially, the monetary policy decisions that would be made by a central bank operating under discretion would be vastly different than those expected by policymakers guided purely by the mandate of the central bank.

The broader issue for policy design is that we are well advised to think outside the realm of traditional macroeconomic policy analysis if we wish to ensure that the institutional framework in place facilitates decisions that are systematic and consistent with good economic outcomes over time. To that end, we should account for the fact that policymakers are human and subject to temptations and biases that would lead to difficulties when they are asked to make decisions with discretion, especially when faced with a muddled mandate, as is the case for the Federal Reserve.

THE COGNITIVE PSYCHOLOGY PERSPECTIVE

Another source of biases that make discretion potentially harmful draws on cognitive psychology. The problem can be briefly illustrated by referring to George Akerlof’s 1990 Ely Lecture on “Procrastination and Obedience.”

The relation to the monetary policy problem becomes obvious when the intertemporal trade-off that defines procrastination is considered. According to Akerlof (1991, p. 1):

Procrastination occurs when present costs are unduly salient in comparison with future costs, leading individuals to postpone tasks until tomorrow without foreseeing that when tomorrow comes, the required action will be delayed yet again.

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The description of the problem exactly reflects the intertemporal challenge embedded in the monetary policy problem when considering the trade-off between unemployment and inflation. At the margin, monetary policy can always reduce the *present* cost of high unemployment by easing policy further. On the other hand, overdoing this and pushing down the unemployment rate too hard only generates a *future* cost. This is the cost associated with rising inflation, which would be expected to materialize with a long lag.

Fear of liftoff can be seen as the manifestation of procrastination in monetary policy. Procrastination describes a behavioral pathology that would appear inconsistent with decisions that properly account for the future cost of today's decisions for action or inaction. This is a pathology that may hamper not only individuals in their private lives but also policymakers. And it is a pathology that may be very difficult to detect when policymakers operate under discretion. In the presence of uncertainty, it may be virtually impossible for an outside observer to distinguish when a discretionary decision represents a deviation from good practice, the result of a behavioral pathology, and when it reflects sound judgment, efficiently incorporating information the policymaker may possess that may not be available to the outside observer. Even when the outlook for the economy would ordinarily call for policy action, an asymmetry of perceived risks may be invoked during a recovery to justify the discretionary decision to delay normalization.

As Akerlof (1991, p. 2) notes, cognitive psychology can help us understand one source of this pathology:

A central principle of modern cognitive psychology is that individuals attach too much weight to salient or vivid events and too little weight to nonsalient events.

Since the Great Recession, the public policy debate has become greatly influenced by the fear of high unemployment. In the current context, the cognitive psychology perspective would identify unemployment as the salient element driving policy decisions, thus explaining fear of liftoff.

A LEGACY OF THE GREAT RECESSION

The inconsistency of the goals of maximum employment and price stability in the Federal Reserve's mandate becomes problematic when the mandate is interpreted in a manner that directly or indirectly places excessive emphasis on maximum employment. Monetary policy acquires an activist bent, familiar from the experience of the 1960s and 1970s. By pushing too hard to lower unemployment when it is perceived to be high, policy sets in motion a stop-go cycle dynamic that ultimately hinders macroeconomic performance.

One way to avoid this problem is by clarifying the Federal Reserve's mandate with legislative action.¹⁰ Another way is for the Federal Reserve to adopt on its own an alternative interpretation of its mandate, one that views price stability as a primary operational objective, based on the rationale that doing so provides the best way to ensure maximum sustainable growth and employment over time. Indeed, this is the interpretation of the mandate that prevailed throughout the Great Moderation era. For a generation that spanned the Fed chairmanships

of Paul Volcker and Alan Greenspan, price stability was seen as a precondition for achieving maximum sustainable employment over the long run and that served to protect against the short-sighted bias that overemphasizes short-term gains in employment.

This was possible precisely because of the traumatic experience associated with the Great Inflation.¹¹ For a generation, high inflation had become the most salient cost in the monetary policy debate, facilitating an interpretation of the Federal Reserve's mandate that appropriately focused on protecting the economy against that malaise over the long run.

This changed during the Great Recession. Without the experience of high inflation in recent memory to serve as a shield, unemployment costs became unduly salient. In essence, the experience of the Great Recession changed the relative weights placed on the incompatible goals of maximum employment and price stability. Unsatisfied with a slow pace of recovery, the Federal Reserve moved toward a more literal interpretation of its mandate, elevating the aversion to temporarily high unemployment and reverting to destabilizing discretion.

On January 25, 2012, the FOMC formalized this shift with the publication of a statement on its long-run objectives and strategy that reiterated its new position:

The Federal Open Market Committee (FOMC) is firmly committed to fulfilling its statutory mandate from the Congress of promoting maximum employment, stable prices, and moderate long-term interest rates. (Board of Governors of the Federal Reserve System, 2012)

In December 2012, three and a half years after the end of the recession, the FOMC even took the unprecedented step of adopting a numerical threshold for the unemployment rate as a formal guide for injecting additional policy accommodation into the economy through QE.

A legacy of the Great Recession has been a shift to a policy framework that places greater emphasis on the goal of maximum employment than had been the case during the Great Moderation era. In this environment, discretionary policy once again risks setting in motion the adverse stop-go policy dynamic experienced in the period before the Great Moderation.

To be sure, it could be suggested that bringing the notion of maximum employment to the forefront as an operational goal for the Federal Reserve is entirely appropriate in the interest of clarity and transparency, given the Federal Reserve's statutory mandate. Indeed, in its statement on long-run objectives, the Committee argued that such clarity enhances transparency and accountability, which are essential in a democratic society. However, the real issue is not to acknowledge the long-run objectives of the Federal Reserve, but rather to adopt an operational framework that ensures that policy can contribute in the best possible manner toward the attainment of these objectives, accounting for the behavioral biases that human nature introduces in the policy process.

THE CASE FOR POLICY RULES

How can systematic monetary policy that robustly contributes to social welfare be best ensured over time? By the end of the twentieth century, vast historical experience had been accumulated on what constitutes best practice in central banking. The adverse consequences of political interference and behavioral biases that give rise to the dynamic inconsistency prob-

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lem—and more broadly the limits of monetary policy—were better recognized. Attitudes shifted away from excessive policy activism, especially after the Great Inflation, giving rise to a rebirth of modern central banking organized on two pillars: an independent central bank with a clear primary mandate to preserve price stability. In numerous economies, this was codified in the law. For example, in the case of the European Central Bank, the 1992 Maastricht Treaty explicitly recognizes that “[t]he primary objective...shall be to maintain price stability.”

In the United States, given the Federal Reserve’s current mandate, its independence is insufficient to ensure systematic policy over time. Even with the best intentions, central bank independence is not enough to protect against human nature, harmful discretion, and political pressure. The question remains how to help the appointed policymakers contribute in a robust manner, accounting for the practical limitations and biases induced by the current institutional environment and human nature.

The answer is policy rules. The central bank should eschew discretion in favor of a transparent, easy-to-monitor strategy—a policy rule. The central bank should heed warnings known for millennia already and follow the discipline demonstrated by Odysseus to overcome the temptation of harmful discretion. The adoption of a policy rule can ensure a proper long-term policy focus, solve dynamic inconsistency problems, and circumvent behavioral biases that hamper policymaking in practice.

The key remaining question should be how to select the rule that should replace the meeting-by-meeting reliance on discretion. The focus should be on the process for designing, evaluating, and implementing a simple and robust policy rule. As is well understood, simple policy rules have strengths and weaknesses relative to optimal, adaptable, rationally designed plans. But theoretical benchmarks of optimality are always based on models with simplifying assumptions that are known not to hold exactly in reality. Acknowledgment of the “suboptimality” of any simple rule relative to an unattainable theoretical benchmark cannot be used as an excuse for defending discretion.

A large body of accumulated research offers guidance on how to evaluate alternative simple rules and assess their robustness in light of the pervasive uncertainties and complexity of the economy.¹² Alternative specifications suggest simple formulas that can preserve price stability over time while being somewhat countercyclical with respect to output and employment. Examples include specifications based on the classic Taylor rule that set the policy rate to equal the natural rate of interest plus a linear function of inflation and the unemployment gap—the difference between the actual level of unemployment and its natural rate. Known limitations of these rules include our ignorance of the natural rates of either the interest rate or the unemployment rate in real time, when policy decisions are made. Other specifications, building on the insights of Knut Wicksell and Milton Friedman about dealing with unknown natural rates, specify that changes of the policy rate respond to inflation and changes in the unemployment rate. The rules can be based on historical data or on short-term economic projections of inflation and economic activity, providing an extensive menu of options that could be considered and evaluated before the preferred rule to be implemented is adopted. Existing evaluation work, based on estimated models, suggests that simple rules can be robust to a range of pitfalls that hamper theoretical optimal policy benchmarks.

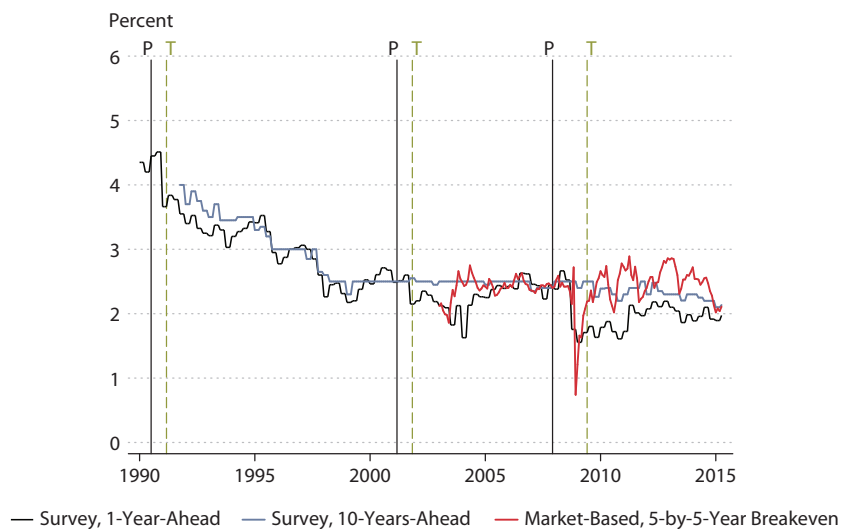
However, in light of the complexity of the economy, the limitations and continuous evolution of our understanding, and the constant adaptation of empirical models available for policy analysis, no fixed rule could be expected to perform equally well at all times. This suggests that discretionary policy should not be replaced with a fixed and immutable simple rule but rather with a framework for selecting a simple robust rule that foresees periodic reviews and adaptation.

The authority to use discretion to decide policy on a meeting-by-meeting basis by appointed Federal Reserve policymakers could be replaced with the authority to use discretion to select the simple policy rule policymakers see as most appropriate on the basis of the available state of knowledge. Given the rigor and expertise available in the Federal Reserve System, the Federal Reserve is arguably best placed to develop the simple rule that (i) reflects the present state of knowledge (and ignorance) and (ii) is robust to error. At the same time, recognizing the complexity and limited understanding of the economic environment, there is merit to reevaluation of the selected simple policy rule and scope for periodic review and adaptation of the simple rule the central bank would commit to adhere to.

Replacing the meeting-by-meeting discretion with a transparent process of selecting and periodically adapting a simple and robust policy rule would ensure that monetary policy is systematic and robustly contributes to social welfare over time while also retaining the flexibility to account for the evolution of our understanding of the economic environment. To render the policymakers accountable and eliminate meeting-by-meeting discretion, the selected rule should be transparent and specified with sufficient detail that an outside observer is able to determine the meeting-by-meeting setting of policy using only public information and without any additional input from the Federal Reserve. For example, if the rule's implementation required use of unobserved concepts, such as the natural rates of interest (r^*) or unemployment (u^*), the methodology for arriving at the pertinent estimates should also be specified in advance to make the rule meaningful and avoid discretion.¹³ Similarly, if the rule uses short-term projections of inflation or unemployment, these could not be projections produced by the Federal Reserve, thereby incorporating judgment in a discretionary manner.

In principle, publication of a simple rule could be legislated along the lines of legislative proposals that have been discussed in recent years.¹⁴ However, legislation of any specific rule or procedure is not necessary and considerable scope for improvement is available for the Federal Reserve under the legislation currently in place. Within its mandate, the Federal Reserve can and would be well advised to embrace and implement improvement on its own.

Within its mandate, the Federal Reserve could publish a simple rule along the lines of its publication of the Committee's principles regarding its longer-run goals and monetary policy strategy. Publishing a simple policy rule, together with the methodology used to select it and the necessary information to replicate and monitor it with publicly available data, would be a quantum leap in enhancing transparency and accountability. By committing to a transparent process of adaptation of the simple rule only after periodic reviews to account for changes in the state of knowledge of the economy, the Federal Reserve would solve the current dynamic inconsistency problems and circumvent behavioral biases that hamper policymaking in practice.

Figure 8**Measures of Inflation Expectations**

NOTE: The 5-by-5-year breakeven rate is derived using prices on Treasury bonds and Treasury inflation-protected securities. The vertical lines denote business cycle peaks (P) and troughs (T).

SOURCE: FRED®, Federal Reserve Economic Data, Federal Reserve Bank of St. Louis for 5-by-5-year breakeven data; Federal Reserve Bank of Philadelphia for survey data.

WHY WORRY NOW?

The publication of a simple rule by the Federal Reserve would solve the monetary policy quandary created in the current institutional environment by discretion and effectively tackle fear of liftoff. Failing to address the problem would slowly but surely result in policy backsliding to the methods and results experienced before the Great Moderation era.

One might wonder why we should worry now, since discretion has been with us for some time—including during the Great Moderation era. The concern arises once we recognize the role of generational dynamics and learning in the macroeconomy. Despite the massive monetary policy easing engineered during and after the Great Recession, and despite the demonstrated reluctance to embark on policy normalization in line with the experience following recessions during the Great Moderation era, inflation expectations remain well anchored. Pertinent survey- and market-based measures of expectations (Figure 8) suggest no adverse consequences on inflationary psychology.

With inflation currently contained, the risks associated with the Federal Reserve's reinterpretation of its mandate to place greater weight on maximum employment are not immediate. The key question is whether the Federal Reserve could continue to maintain its reputation as a bulwark of price stability, despite the greater emphasis it appears to currently attach to maximum employment, once inflation starts rising with the continuing expansion of the economy.

Figure 9
Long-Term Inflation Expectations



NOTE: Long-term inflation expectations proxy in FRB/US model.

SOURCE: Federal Reserve Board FRB/US model database.

At present, the Federal Reserve continues to benefit from the reputation it slowly acquired over a generation with systematic policy that stressed the primacy of price stability.

However, it would be a grave error to take for granted the stability of inflation expectations currently observed. Reputation is earned and expensed over time. Inflation expectations are well anchored until they are not. In the absence of systematic policy, rising inflation could lead to rapid deterioration of the Federal Reserve's reputation—a significant cost that would tax society in the future and would have to be tackled by future policymakers. The historical evolution of the proxy of long-term inflation expectations used in the Federal Reserve's FRB/US model (Figure 9) can serve as a reminder of this pattern. The figure highlights both the process of unanchoring inflation expectations in the 1960s and 1970s—the penalty of activist policies overemphasizing maximum employment during that period—and the slow improvement that spanned much of the chairmanships of Paul Volcker and Alan Greenspan.

ASYMMETRIC RISKS AND LEARNING

The long period of unchanged policy rates experienced in recent years may make the delay in embarking on the policy normalization process especially costly in the current context. This is due to the dynamic uncertainty regarding the impact of raising policy rates on inflation and unemployment—the so-called multiplier uncertainty. The effectiveness of a change in policy rates is always uncertain and recent history is always helpful in calibrating it with greater

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accuracy. The propensity for policy mistakes is smaller when policymakers can be more confident of the effect of the incremental increase in policy rates on inflation one or two years later. With policy rates unchanged near zero since 2008, a significant benefit of an earlier liftoff would be the added information about the effectiveness of the Federal Reserve's normalization strategy.¹⁵

Consider the two possibilities for error following an increase in the policy rates in the current environment. If the tightening were to prove more effective than expected, the implication would be that additional tightening could be introduced at a slower pace. Given the immense policy accommodation currently in the system, the associated cost would be small. On the other hand, if the tightening were to prove less effective than expected, much more tightening and at a faster pace would be needed than anticipated, at a significantly higher associated cost.¹⁶

Fear of liftoff raises the odds that the Fed will soon be confronted with a costly dilemma: Tighten policy abruptly to control inflation, precipitating a recession? Or let the inflation genie out of the bottle to avoid recession? The greater the delay, the greater the risk that an orderly unwinding of monetary policy accommodation becomes virtually impossible.

MARTIN'S PUNCH BOWL

Recounting the monetary policy problem faced by the Federal Reserve on an earlier occasion, six decades ago, provides an appropriate end to our historical journey. Liftoff after the recession that ended in May 1954 occurred in April 1955, while the economy was recovering but while employment conditions fell short of what many considered compatible with full employment at that time.¹⁷ As Chairman William McChesney Martin Jr. (1955) explained later that year, the Federal Reserve did not expect to be applauded for restricting credit to protect against the threat of future inflation:

In the field of monetary and credit policy, precautionary action to prevent inflationary excesses is bound to have some onerous effects—if it did not it would be ineffective and futile. Those who have the task of making such policy don't expect you to applaud. The Federal Reserve, as one writer put it, after the recent increase in the discount rate, is in the position of the chaperone who has ordered the punch bowl removed just when the party was really warming up.

Discretionary decisions bound to have some onerous effects in the present will always face hesitation and resistance when the anticipated benefits are more uncertain and in the distant future. Liftoff is the monetary policy equivalent of removing the punch bowl from the party.

The basic question has not changed in the 60 years since those remarks: How can we ensure that the Federal Reserve will consistently act in a systematic, forward-looking manner promoting stability and prosperity over time? Monetary policymaking can become more robust, drawing on lessons from expanded horizons outside the realm of traditional economic analysis about the challenges and limitations posed by the institutional environment and human nature. Discretionary policy should be eschewed to ensure systematic policy. However, meeting-by-

meeting discretion need not be replaced with a fixed and immutable simple rule, since any simple rule would require some adjustment over time, but rather with a framework for selecting a simple robust rule that foresees periodic reviews and adaptation.

Legislation could help Federal Reserve policymakers by providing a clearer mandate and guidelines toward the adoption of a policy rule. But legislation would not be needed if the Federal Reserve embraces improvements that can be implemented under current law. Within its mandate, the Federal Reserve could publish a simple rule along the lines of the publication of its longer-run goals, together with information needed to replicate and monitor it. In this manner, the Federal Reserve would eschew meeting-by-meeting discretion. The Federal Reserve would retain the discretionary authority for periodic review and adaptation of its rule, using the expertise available in the Federal Reserve System. This would be a quantum leap in enhancing transparency and accountability toward securing the Federal Reserve's contribution to long-lasting stability and prosperity in the nation. ■

NOTES

- ¹ Williamson (2015) reviews challenges posed by the normalization question. In remarks at the March 20, 2015, meeting of the Shadow Open Market Committee, John Taylor characterized this concern as monetary policy having entered a “strategy-free zone” (Taylor, 2015). Recent examples of calls to change the legal framework of the Federal Reserve include the Federal Reserve Accountability and Transparency Act of 2014 and the Financial Regulatory Improvement Act of 2015 (U.S. Congress, 2014, 2015).
- ² Such questions have been part of the extensive “rules vs. discretion” debate over several decades. See Fischer (1990) for an early survey, Tavlas (2015) for a recent historical treatment, and McCallum (2004) and Goodfriend (2014) for discussions focused on the Federal Reserve.
- ³ Bernanke (2004) offers a concise review of the likely causes of the Great Moderation. The historical analysis of the Federal Reserve presented by Hetzel (2008), Meltzer (2009), and Lindsey (forthcoming) offers more extensive discussions of the evolution of the Federal Reserve’s monetary policy framework.
- ⁴ Unless otherwise stated, the point of reference is the date the lecture was delivered (June 3, 2015). The latest data available at that time were used.
- ⁵ Expressing this additional easing in numerical terms comparable to conventional reductions in policy rates is not immediate, but estimates suggest that the additional accommodation engineered by the Federal Reserve with unconventional policy could be equivalent to a few hundred basis points of conventional policy easing (D’Amico et al., 2012, and Engen, Laubach, and Reifschneider, 2015).
- ⁶ See, e.g., Orphanides (2003) and Orphanides and Williams (2005).
- ⁷ Chair Yellen’s remarks on normalizing monetary policy offer a recent example (Yellen, 2015).
- ⁸ The estimate shown for 2004, for example, is the one published in 2004, which is somewhat higher than the estimate for 2004 published in January 2015.
- ⁹ The central tendency excludes the three highest and three lowest projections provided.
- ¹⁰ See, e.g., Orphanides (2014).
- ¹¹ Lindsey, Orphanides, and Rasche (2005) document the considerations behind Volcker’s reform in October 1979.
- ¹² Taylor and Williams (2010) present a comprehensive survey. In recent years, the development of model databases, such as that of Wieland et al. (2012), has greatly simplified examining robustness properties of alternative simple rules across large numbers of estimates models. See Orphanides and Wieland (2013) for a recent application. Using the Federal Reserve’s FRB/US model, Tetlow (2015) demonstrates the critical nature of tracking the robustness of alternative rules even across alternative vintages of the same model.
- ¹³ The example provided in footnotes 4 and 5 in Yellen (2015) usefully illustrates the need for sufficient detail. Yellen compared actual policy with the prescription that could be obtained from a Taylor rule whose implementation requires use of specific values for both r^* and u^* . The form of the rule Yellen selected was $f = r^* + \pi + 0.5(\pi - 2) + 1.0(u - u^*)$, where f denotes the federal funds rate, π the rate of inflation using a core consumer price index, and u the unemployment rate. Yellen noted that this rule was consistent with actual policy at the time of the speech if the values $r^* = 0$ and $u^* = 5.0$ were chosen. With the Taylor rule, if assumptions regarding the natural rates could be chosen in a discretionary fashion, any discretionary decision could be described as consistent with the rule.
- ¹⁴ See, e.g., the Federal Reserve Accountability and Transparency Act of 2014 (U.S. Congress, 2014).
- ¹⁵ Since the Federal Reserve has suggested that it intends to rely on increases in policy rates to unwind the accommodation not only due to reductions in interest rates but also due to the expansion of the Federal Reserve’s balance sheet, the multiplier uncertainty on policy rates is of even greater importance.
- ¹⁶ This is an example of asymmetries in learning and the value experimentation under uncertainty (Wieland, 2000).
- ¹⁷ The discount rate was raised from 1½ to 1¾ percent on April 13, 1955. The unemployment rate registered 5.0 percent in March 1955, while 4 percent was widely viewed as the rate corresponding to full employment at the time.

REFERENCES

- Akerlof, George. "Procrastination and Obedience." *American Economic Review*, May 1991, 81(2), pp. 1-19.
- Bernanke, Ben S. "The Great Moderation." Presented at the meetings of the Eastern Economic Association, Washington, DC, February 20, 2004; <http://www.federalreserve.gov/BOARDDOCS/speechES/2004/20040220/>.
- Bernanke, Ben S. "Monetary Policy Since the Onset of the Crisis." Presented at the Federal Reserve Bank of Kansas City Economic Policy Symposium *The Changing Policy Landscape*, Jackson Hole, WY, August 31, 2012; https://www.kansascityfed.org/publicat/sympos/2012/Bernanke_final.pdf.
- Board of Governors of the Federal Reserve System. "Statement on Longer-Run Goals and Monetary Policy Strategy." "Press Release." January 25, 2012; <http://www.federalreserve.gov/newsevents/press/monetary/20120125c.htm>.
- D'Amico, Stefania; English, William; Lopez-Salido, David and Nelson, Edward. "The Federal Reserve's Large-Scale Asset Purchase Programs: Rationale and Effects." *Economic Journal*, October 2012, 122(564), pp. F415-46.
- Engen, Eric; Laubach, Thomas and Reifschneider, David. "The Macroeconomic Effects of the Federal Reserve's Unconventional Monetary Policies." Finance and Economic Discussion Series Working Paper 2015-005, Federal Reserve Board, January, 2015; <http://www.federalreserve.gov/econresdata/feds/2015/files/2015005pap.pdf>.
- Fischer, Stanley. "Rules versus Discretion in Monetary Policy," in Benjamin M. Friedman and Frank H. Hahn, eds., *Handbook of Monetary Economics*, Volume II. Chap. 21. Amsterdam: Elsevier, 1990, pp. 1155-84.
- Goodfriend, Marvin. "Lessons from a Century of FED Policy: Why Monetary and Credit Policies Need Rules and Boundaries." *Journal of Economic Dynamics and Control*, December 2014, 49, pp. 112-20.
- Hetzel, Robert. *The Monetary Policy of the Federal Reserve: A History*. New York: Cambridge University, 2008.
- Lindsey, David E. *A Century of Monetary Policy at the Fed: Ben Bernanke, Janet Yellen, and the Financial Crisis of 2008*. London: Palgrave Macmillan, 2016 (forthcoming).
- Lindsey, David E.; Orphanides Athanasios and Rasche, Robert. "The Reform of October 1979: How It Happened and Why." *Federal Reserve Bank of St. Louis Review*, March/April 2005, 87(2 Part 2), pp. 187-235; <https://research.stlouisfed.org/publications/review/05/03/part2/MarchApril2005Part2.pdf>.
- McCallum, Bennett. "Misconceptions Regarding Rules vs. Discretion for Monetary Policy." *Cato Journal*, Winter 2004, 23(3), pp. 365-72; <http://object.cato.org/sites/cato.org/files/serials/files/cato-journal/2004/1/cj23n3-5.pdf>.
- Martin, William M. Jr. "Address before the New York Group of the Investment Bankers Association of America." New York, October 19, 1955; <http://www.federalreservehistory.org/Media/Material/People/113-140>.
- Meltzer, Allan. *A History of the Federal Reserve*. Volume 2. Chicago: University of Chicago Press, 2009.
- Orphanides, Athanasios. "The Quest for Prosperity without Inflation." *Journal of Monetary Economics*, April 2003, 50(3), pp. 633-63.
- Orphanides, Athanasios. "The Need for a Price Stability Mandate." *Cato Journal*, Spring/Summer 2014, 34(2); <http://object.cato.org/sites/cato.org/files/serials/files/cato-journal/2014/5/cato-journal-v34n2-4.pdf>.
- Orphanides, Athanasios and Wieland, Volker. "Complexity and Monetary Policy." *International Journal of Central Banking*, January 2013, 9(1), pp. 167-203; <http://www.ijcb.org/journal/ijcb13q0a8.pdf>.
- Orphanides, Athanasios and Williams, John C. "The Decline of Activist Stabilization Policy: Natural Rate Misperceptions, Learning, and Expectations." *Journal of Economic Dynamics and Control*, 2005, 29(11), pp. 1927-50.
- Tavlas, George. "In Old Chicago: Simons, Friedman, and the Development of Monetary-Policy Rules." *Journal of Money, Credit, and Banking*, February 2015, 47(1), pp. 99-121; <http://onlinelibrary.wiley.com/doi/10.1111/jmcb.12170/abstract>.
- Taylor, John. "Getting Back to a Rules-Based Monetary Strategy." Presented at the conference "Getting Monetary Policy Back on Track," presented by the Shadow Open Market Committee, Princeton Club, New York, March 20, 2015; http://web.stanford.edu/~johntayl/2015_pdfs/SOMC-talk%20_Taylor-3-20-15.pdf.
- Taylor, John, and John C. Williams. "Simple and Robust Rules for Monetary Policy," in Benjamin M. Friedman and Michael Woodford, eds., *Handbook of Monetary Economics*. Volume 3. Chap. 15. Amsterdam: Elsevier, 2010, pp. 825-59.

Orphanides

- Tetlow, Robert. "Real-Time Model Uncertainty in the United States: 'Robust' Policies Put to the Test." *International Journal of Central Banking*, March 2015, 11(1), pp. 113-55; <http://www.ijcb.org/journal/ijcb15q2a4.pdf>.
- U.S. Congress. "Amendments to the Federal Reserve Act." Public Law 95-188, November 16, 1977; <http://www.gpo.gov/fdsys/pkg/STATUTE-91/pdf/STATUTE-91-Pg1387.pdf>.
- U.S. Congress. "Federal Reserve Accountability and Transparency Act of 2014." H.R. 5018, July 30, 2014; <https://www.congress.gov/bill/113th-congress/house-bill/5018>.
- U.S. Congress. "The Financial Regulatory Improvement Act of 2015." http://www.banking.senate.gov/public/index.cfm?FuseAction=Files.View&FileStore_id=8d9a5138-10a3-4a53-a48f-86ce373aa880.
- Wieland, Volker. "Learning by Doing and the Value of Optimal Experimentation." *Journal of Economic Dynamics and Control*, April 2000, 24(4), pp. 501-34.
- Wieland, Volker; Cwik, Tobias; Mueller, Gernot J.; Schmidt, Sebastian and Wolters, Maik. "A New Comparative Approach to Macroeconomic Modeling and Policy Analysis." *Journal of Economic Behavior and Organization*, August 2012, 83(3), pp. 523-41.
- Williamson, Stephen. "Monetary Policy Normalization in the United States." Federal Reserve Bank of St. Louis *Review*, Second Quarter 2015, 97(2), pp. 87-108; <https://research.stlouisfed.org/publications/review/2015/q2/Williamson.pdf>.
- Yellen, Janet. "Normalizing Monetary Policy: Prospects and Perspectives." Presented at the Federal Reserve Bank of San Francisco, San Francisco, CA, March 27, 2015; <http://www.federalreserve.gov/newsevents/speech/yellen20150327a.htm>.

Human Capital and Development

Rodolfo E. Manuelli

Perhaps no question has attracted as much attention in the economics literature as “Why are some countries richer than others?” In this article, the author revisits the “development problem” and provides some estimates of the importance of human capital in accounting for cross-country differences in output per worker. His results suggest that human capital has a central role in determining the wealth of nations and that the quality of human capital varies systematically with the level of development. (JEL E00, O040)

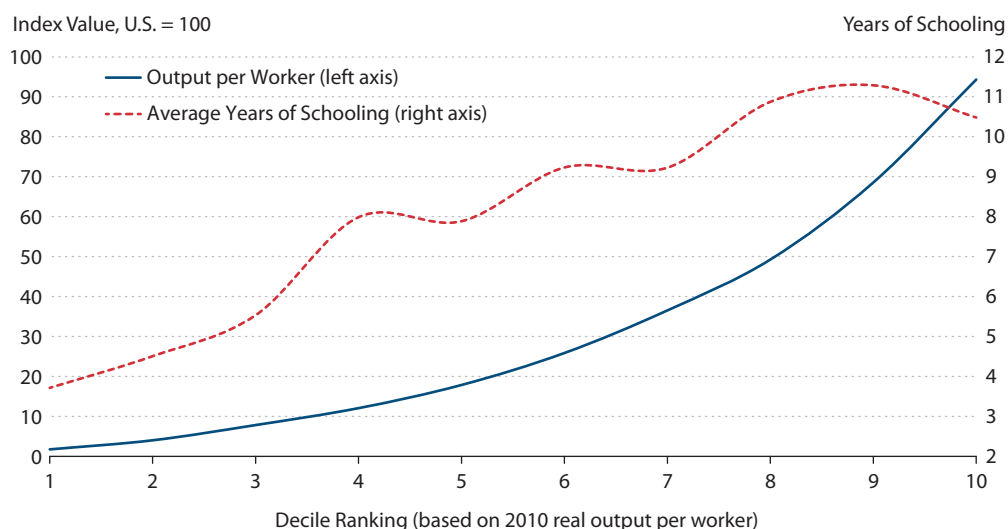
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Why are some countries richer than others? This question is central to the current research agenda in economics. The difference in output per worker between “rich” countries (defined as the top 10 percent of countries in terms of labor productivity) and “poor” countries (the bottom 10 percent) is very large: The productivity of a typical worker in a poor country is about 2 percent of the productivity of a worker in a rich country. It is only natural to try to understand the factors accounting for this gap and, more importantly, whether this understanding provides some guidance about the types of policies that can help poor countries improve their economic situation. Put differently, economists (and policymakers) would like to find the “engine of growth.”

In this article, I describe some recent research on the role of human capital in accounting for the cross-country differences in output per worker. One key feature of this approach to the development problem is its emphasis on viewing human capital as two-dimensional with both a qualitative and a quantitative component. Thus, in this view of human capital as a central factor in explaining differences in output per worker, the amount of human capital of a high school graduate from, say, Rwanda need not be the same as the amount of human capital of a U.S. high school graduate. In what follows, I discuss the role and quantitative importance of human capital in accounting for a country’s level of development.

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Figure 1**Average Years of Schooling and Real Output per Worker (by decile)**

SOURCE: Penn World Table (version 8.0; <http://www.rug.nl/research/ggdc/data/pwt/>) and Barro and Lee (2010).

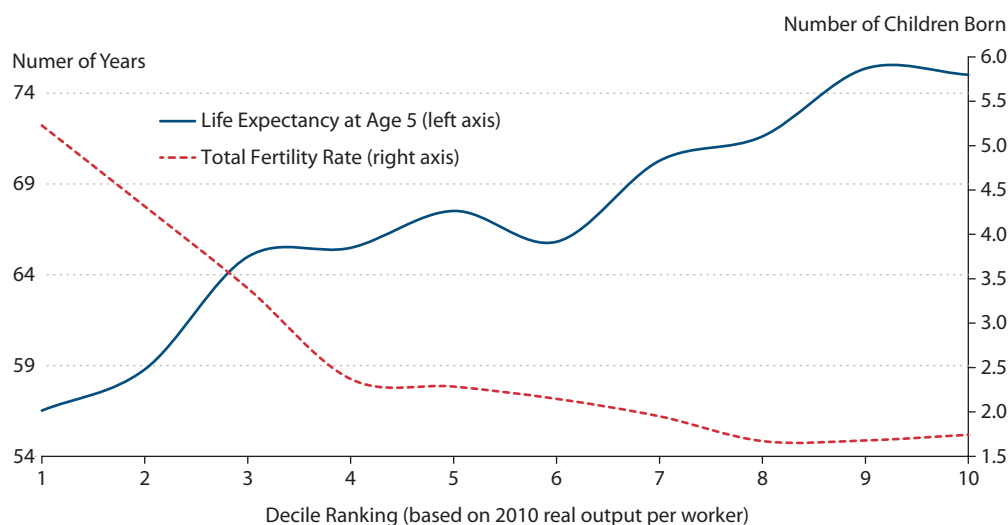
EVIDENCE

Figure 1 shows some aggregate data for all the countries in the world, circa 2010, grouped by deciles according to their level of output per worker. The average country in the top decile (the average rich country) has an output per worker that is almost 95 percent of the U.S. level. In contrast, a worker in the median country—the average country in the 5th to 6th decile—produces about one-quarter of the amount produced by a U.S. worker; this ratio drops to 1.7 percent for the typical worker in a poor country.

What accounts for these output differences? Figure 1 also displays the average years of schooling for the typical worker, and a clear pattern is evident: Richer countries have a more-educated labor force. Figure 2 shows two other measures correlated with output per worker: life expectancy at 5 years of age and total fertility rate. There is a clear association between these variables and development: Richer (more productive) countries have a better-educated workforce that is, on average, healthier (as measured by life expectancy) and has a lower fertility rate.

It is tempting to view this evidence as a recipe for growth. Looking at the data, it seems that if only countries had more successful educational systems, better health care, and some form of birth control, this combination would result in potentially large increases in output per worker. This approach ignores the fact that individuals in every country make their own choices about schooling, health care, and fertility. Thus, to induce changes in any of these variables it is necessary to understand the forces and constraints that account for the observed pattern of human capital investment.

Figure 2
Life Expectancy at Age 5 and Total Fertility Rate



SOURCE: Data from United Nations (2013).

A reasonable starting point on the question of development (or lack of it) seems to be to ask the following question: “What factors induce individuals in poor countries (the bottom 10 percent in productivity) to attend school for only 3.7 years, to have almost 5.2 children per woman, and to live in an environment where life expectancy at 5 years of age falls short of 57 years?” These circumstances are in contrast to those of the average individual in a rich country: almost 11 years of schooling, only 1.7 children per woman, and a life expectancy (at age 5) of 75 years. To find solutions to bettering the poor country’s scenario, it is necessary to develop a model that captures how individuals make choices about schooling, fertility, and health care and how factors that are exogenous (to them) influence those choices.

A SIMPLE APPROACH

As a starting point, I study a simple model that captures the aggregate impact of schooling and, more generally, human capital accumulation decisions. The model includes differences in both the *quantity* of human capital (measured as years of schooling, the red line in Figure 1) and the *quality* of human capital (which can be measured only very indirectly). Even though including human capital quality in the calculations complicates the interpretation of the results—as quality is not directly observable—I argue that explicitly accounting for quality differentials is essential to explaining the data in Figure 1.

Consider the simplest (and somewhat unrealistic) model: Individuals do not choose their schooling, and the quality of schooling is the same in all countries. Several estimates (e.g.,

those of Bils and Klenow, 2000, and Psacharopoulos and Patrinos, 2004) show the impact of education: An additional year of schooling increases individual income about 10 percent.¹ In this case, and absent differences in quality, the level of human capital per worker in country i , defined as the return to schooling, is

$$(1) \quad h_i = h^q e^{r_s s_i},$$

where r_s is the rate of return to schooling ($r_s = 0.10$ in this example), s_i is years of schooling, and h^q is a constant that captures the common quality level of schooling.

I consider a simple technology to develop a framework adequate to understanding the differences in the level of output per worker. This technology maps capital per worker, k , human capital per worker, h , and total factor productivity (TFP), which is denoted by z , into output per worker. The standard in the macro literature is the Cobb-Douglas specification that states that output per worker is given by

$$y_i = z_i k_i^\alpha h_i^{1-\alpha}, \quad 0 < \alpha < 1.$$

As a first pass, assume that all countries face the same cost of capital, r^* , and that firms choose the level of capital to equate its cost to its marginal product. Formally, this requires that

$$r^* = \alpha z_i k_i^{\alpha-1} h_i^{1-\alpha},$$

which implies that the capital-to-human capital ratio is

$$\frac{k_i}{h_i} = \left(\frac{\alpha z_i}{r^*} \right)^{\frac{1}{1-\alpha}}$$

and, hence, that output per worker is

$$(2) \quad y_i = z_i \left(\frac{\alpha z_i}{r^*} \right)^{\frac{\alpha}{1-\alpha}} h_i.$$

Thus, in this view, the differences in output per worker are driven by differences in TFP, z_i , and differences in human capital per worker, h_i . To match the data in Figure 1, it is convenient to express output per worker in country i as a ratio of the U.S. level. The ratio for the average poor country, where output per worker is about 1.7 percent of that in the United States, which is normalized to 1, is expressed as

$$\frac{1}{0.017} = \frac{y_R}{y_P} = \left(\frac{z_R}{z_P} \right)^{\frac{1}{1-\alpha}} \frac{h_R}{h_P}.$$

If the average worker in a poor country has 3.7 years of schooling, $s_p = 3.7$, and the average worker in the United States has 14 years of schooling, $s_R = 14$, equation (1) can be used to estimate human capital per worker in each country. In this case, I find that $h_R/h_p = 2.8$. If $\alpha = 1/3$,

which is a standard estimate of capital share, then the estimate of the (unexplained) differences in productivity is

$$\frac{z_R}{z_P} = \left(\frac{1}{0.017} \times \frac{1}{2.8} \right)^{2/3} = 7.6.$$

According to these calculations, the productivity of the average firm in a poor country is about 13 percent of the productivity of an average U.S. firm. It is this type of calculation that led Parente and Prescott (2000) to dismiss human capital as a major force in accounting for differences in productivity.²

Is this a reasonable productivity estimate? It implies that, given the same type of equipment and “effective” labor input (measured as individuals with a given level of schooling), there are some country-specific environmental factors that result in U.S. inputs yielding a productivity level more than seven times the level in a poor country. This is a large difference that seems to exceed the micro estimates.

How would these calculations—and the estimate of the TFP gap—change if the quality of human capital differed across countries? To capture this idea, I modify equation (1) and add a qualitative component. Formally, the level of human capital per worker is given by

$$(3) \quad h_i = h_i^q e^{r_i s_i},$$

where h_i^q is the quality of human capital in country i for a given level of schooling. In this case, the estimates of the differences in productivity (paralleling the previous calculation) yield

$$\frac{z_R}{z_P} = \left(\frac{1}{0.017} \times \frac{1}{2.8} \right)^{2/3} \frac{h_P^q}{h_R^q}$$

and, hence, the higher the quality gap (i.e., the smaller the ratio h_P^q/h_R^q), the smaller the estimated differences in productivity.

At this point, the simple approach suggests that explaining differences in output requires understanding why individuals in a poor country acquire less schooling than individuals in a rich country (i.e., why is $s_P < s_R$?) and, if possible, determining (and estimating) the differences in quality (i.e., h_P^q and h_R^q).

A significant amount of research in macro development has been directed toward developing models that explain individual choices along the quantity (e.g., schooling) and quality dimensions.

In this discussion, I ignore the differences in the price of capital, which imply differences in the rental price of capital r^* , as a potential determinant of cross-country differences in labor productivity. Even though the simple theory sketched above (see equation (2)) implies that the cost of capital influences output per worker, the evidence shows no clear pattern: Capital is relatively cheap in the top two deciles but shows no clear trend across the world distribution. Even though I ignore these differences in the description of the forces that determine the variability of output per worker, I include the impact of differences in the price of capital in the quantitative exercise that follows.

MACROECONOMIC ENVIRONMENT AND HUMAN CAPITAL

Moving beyond simple calculations makes it necessary to be explicit about which features of an economic environment could potentially induce individuals to (i) choose more or less schooling (and on-the-job training [OJT]) and (ii) select different qualities of both education and knowledge acquired on the job. In this section, I show that cross-country differences in productivity can result in cross-country differences in schooling and human capital. To this end, I describe a simplified model of the simultaneous choice of schooling quantity and quality as well as OJT.³

I assume that accumulation of human capital during the *schooling period* satisfies

$$\dot{h}(a) = z_h h(a)^{\gamma_1} x_s^{\gamma_2}, \quad \text{with } \gamma = \gamma_1 + \gamma_2 \in (0,1),$$

where x is the amount of market goods (i.e., teachers, buildings, textbooks) allocated to education and $h(a)$ is the level of human capital that an a -year-old student possesses.⁴ The parameter z_h corresponds to innate ability, and the specification captures the idea that students with higher ability are better able to turn school resources into knowledge. Finally, the restriction that $\gamma \in (0,1)$ is consistent with the view that there exist decreasing returns to scale in education. In addition to the accumulation of human capital attained in school, children at age 6 enter the school system with a certain level of human capital, denoted h_E , which I view as early childhood human capital.

If a student stays in school for s periods and the school quality is x_s , his level of human capital at the end of schooling is given by

$$h(s) = \left[h_E^{1-\gamma} + (1-\gamma_1) z_h x_s^{\gamma_2} s \right]^{\frac{1}{1-\gamma}}.$$

This specification shows that for a given level of schooling, s , individuals who either have a higher level of early childhood human capital (higher h_E) or attend higher-quality schools (higher x_s) have a higher level of human capital. Thus, schooling and human capital need not be perfectly correlated as the relative cost of time and goods varies across countries.

So far, I have taken both the quality and the quantity of schooling as given, but in any reasonable model they should be endogenous. To develop a theory of how individuals choose both dimensions of schooling, it is necessary to be explicit about their objectives. In this article, and as a first approximation, I assume that individuals maximize the present discounted value of their lifetime income.⁵

With this view, an individual chooses the length of schooling, s , and the quality of schooling, x_s , to maximize the discounted value of lifetime income. As an intermediate step, consider the problem solved by an individual after leaving school and joining the workforce. If the discount rate (interest rate) is r , the worker chooses how to allocate time and goods to solve

$$(4) \quad V(h, s) = \max_{x, n} \int_s^R e^{-r(a-s)} [wh(a)(1-n(a)) - x_w(a)] da,$$

subject to

$$(5) \quad \dot{h}(a) = z_h [n(a)h(a)]^{\gamma_1} x_w(a)^{\gamma_2} - \delta_h h(a), \quad a \in (s, R),$$

where a fraction $n(a)$ of the time is devoted to OJT and, hence, $1 - n(a)$ is the effective fraction of the time that the worker allocates to producing. Here, $x_w(a)$ is the amount of market goods used in the production of human capital, R is the retirement age, and w is the wage per unit of human capital.⁶ The specification of the OJT technology (equation (5)) views the process of acquiring more human capital as one that uses time on the job given a level of human capital, $n(a)h(a)$, and material resources, $x_w(a)$, to increase a worker’s human capital. For example, if an individual spends an hour per day learning to use a computer program, $n(a)$ would be approximately 1/8 and $x_w(a)$ is the value of the resources (services of computers, buildings, and supervisor’s time) used in the process.

It is possible to show (see the appendix) that the solution to the income maximization problem, given $h(s)$ is

$$V(h(s), s) = w \frac{m(s; r)}{r + \delta_h} h(s) + w^{\frac{1-\gamma}{1-\gamma}} C \int_s^R e^{-r(t-s)} m(t; r)^{\frac{1}{1-\gamma}} dt,$$

where

$$m(t; r) = 1 - e^{-(r+\delta_h)(R-t)}$$

is a discount factor and C is a constant.

It is useful to note the lifetime pattern of the effective labor supply implied by this model. The effective labor supply—that is, labor supplied to the market—is $h(a)(1 - n(a))$. It is possible to show that these two endogenous choices have the following properties:

- (i) The level of human capital, $h(a)$, initially increases and peaks at some intermediate age; thereafter, it decreases very slightly until retirement.
- (ii) The fraction of the time allocated to production, $1 - n(a)$, increases over an individual’s lifetime and is close to 100 percent of the workweek when a worker reaches middle age.

These two properties of the solution imply that a young worker supplies less human capital than a middle-aged worker because of differences in OJT even if both workers have exactly the same level of formal education. The simple model outlined previously is consistent with the observation that the curve for income earned by an individual over a lifetime has an inverted-U shape.

How should this income-maximizing individual choose the schooling variables? Consistent with the view that economic agents maximize lifetime income, an individual chooses the length of the schooling period, s , and the quality of schooling, x_s , to maximize the net present value of income,

$$\max_{x_s, s} V(h(s), s) - \frac{e^{rs} - 1}{r} x_s,$$

subject to

$$h(s) = [h_E^{1-\gamma_1} + (1-\gamma_1)z_i x_s^{\gamma_2} s]^{\frac{1}{1-\gamma_1}}.$$

It is possible to show that under reasonable parameter restrictions the solution has the property that both quantity (as measured by s) and quality (as indexed by x_s) increase with wages.

It is relatively simple to relate wages—the proximate driver of individual choices of schooling and quality of human capital—to aggregate productivity. If the production function of goods is Cobb-Douglas, the *wage rate per unit of human capital* in country i is

$$w_i = z_i \left(\frac{\alpha z_i}{r^*} \right)^{\frac{\alpha}{1-\alpha}},$$

which is increasing in productivity.

It follows that in countries with high productivity (i.e., high z_i), the return to human capital is higher and, as a consequence, workers in such countries choose more and better schooling. Thus, this more general view has two important implications. First, it can potentially reconcile the macro estimates of differences in output per worker with the micro estimates of productivity differentials. Second, it can provide a measure of the amplification impact of increases in productivity on both levels of schooling and quality.

Before I can use the model to make quantitative predictions, it is necessary to describe how output per worker depends on features of the economy. As assumed earlier, total output depends on total capital, $K(t)$, and total effective human capital, $H^e(t)$. If the population is growing at rate γ and if expected lifetime is T , it follows that the number of individuals of age a at time t is

$$\eta(a, t) = \frac{\gamma}{1 - e^{-\gamma T}} e^{-\gamma a} N(t),$$

where $N(t)$ is the population size at time t . The size of the workforce, $F(t)$ is the number of individuals between the ages of s and R . Thus,

$$F(t) = \frac{\gamma}{1 - e^{-\gamma T}} \left(\int_s^R e^{-\gamma a} da \right) N(t) = \frac{e^{-\gamma s} - e^{-\gamma R}}{1 - e^{-\gamma T}} N(t),$$

and average effective human capital per worker is

$$(6) \quad \bar{h}^e(t) = \frac{H^e(t)}{F(t)} = \frac{\gamma}{e^{-\gamma s} - e^{-\gamma R}} \int_s^R h(a) (1 - n(a)) e^{-\gamma a} da.$$

Output per worker is then

$$y(t) = z_i k(t)^\alpha (\bar{h}^e(t))^{1-\alpha},$$

where

$$k(t) = \frac{K(t)}{F(t)}$$

is capital per worker.

Equation (6) reveals that, in addition to the impact of productivity differences on individual choices of schooling (both quantity and quality) and OJT, differences in population growth rates across countries, γ , mortality, T , and retirement, R , have a direct impact on output. It is particularly interesting that in countries with a fast-growing population, a relatively large fraction of their workforce is “young”; and since young individuals have lower human capital than middle-aged individuals in this model, the average level of human capital is lower relative to countries with slow population growth.

The model just described can be generalized, allowing for (i) an endogenous choice of early childhood human capital (chosen by parents and related, principally, to health) and (ii) limitations on the effective working lifetime as the result of expected mortality. Generalizations along these lines are reported by Manuelli and Seshadri (2014).

DEVELOPMENT ACCOUNTING

In this section, I explore the consequences of the assumption that individuals respond to economic incentives when they accumulate human capital and to what extent it changes the relatively large estimates of the productivity gap between rich and poor countries found earlier. To this end, I use a version of the model described previously to estimate productivity in the average country of each decile of the world income per worker distribution. To be precise, I take demographic variables, ψ (total fertility rate), T (life expectancy), R (retirement age), and the price of capital (p_k), for the average country in each decile as given, and I choose the level of TFP for each decile (the z variable) so that the model’s predictions for output per worker match the data. However, this specification does not constrain the predictions of the model regarding years of schooling and expenditures on education—a rough measure of quality—to be consistent with the data. One way to evaluate the performance of this theoretical framework is to compare its predictions about the unconstrained variables—schooling and expenditures—with the data.

Table 1 presents the predictions of the model and the data for both schooling, s , and the fraction of output allocated to educational expenditures, x_e . For these two variables, Table 1 reports both the actual values—labeled “Data”—and the predictions of the model.

The model performs fairly well in matching the two variables that it predicts: schooling and expenditures in formal education. The predictions for schooling are close to the data, although they tend to overpredict educational attainment for the richer set of countries. In terms of a rough measure of quality such as schooling expenditures (measured as a fraction of output), the model actually underpredicts investment at the high end of the world income distribution and slightly overpredicts expenditures for the poor countries.

The most striking results are the estimates of TFP. In this model, TFP in the poorest countries (i.e., countries in the lowest decile of the world income distribution) is estimated to be

Table 1**Output and Schooling: Data and Model**

Decile	y		s		x_s	
	Relative to U.S.	$TFP(z_i)$	Data	Model	Data	Model
90-100	0.872	0.97	10.36	11.68	5.1	3.2
80-90	0.743	0.95	9.77	11.50	5.7	3.7
70-80	0.508	0.94	9.79	10.32	4.6	2.5
60-70	0.348	0.92	8.79	9.47	4.7	3.3
50-60	0.251	0.91	8.45	8.70	3.9	3.0
40-50	0.187	0.81	6.29	8.49	4.6	4.0
30-40	0.125	0.85	7.64	7.06	4.7	4.0
20-30	0.077	0.79	5.18	5.98	3.8	5.2
10-20	0.037	0.71	3.61	4.25	4.6	5.8
0-10	0.019	0.63	2.75	2.83	3.6	4.3

Table 2**Understanding Human Capital Differences**

Decile	Relative to U.S.			Contribution (shares)		
	y	h_E	\bar{h}	OJT	Schooling	Early childhood
90-100	0.872	0.93	0.90	0.43	0.48	0.08
50-60	0.251	0.67	0.41	0.45	0.42	0.13
0-10	0.019	0.28	0.05	0.32	0.24	0.44

63 percent of U.S. TFP. This is in stark contrast to the results of Parente and Prescott (2000), Hall and Jones (1999), and Klenow and Rodriguez-Clare (1997), who find that large differences in TFP are necessary to account for the observed differences in output per worker. By comparison, the corresponding number in their studies is around 25 percent, and my estimate from the naive exercise is 14 percent. Thus, my estimate of TFP in the poorest countries is more than two and a half times higher.

If one uses the model to compute the elasticity of output with respect to TFP when all endogenous variables are allowed to reach their new steady state (over the very long run), my estimate of this elasticity is around 5.7. Thus, according to the model, changes in TFP have a large multiplier effect on output per worker (Table 2).⁷

The practical implication of this finding is that, once differences in the quality of human capital are allowed for, standard macro models appear more consistent with the micro evidence, which suggests that the differences in productivity at the micro level between rich and poor countries are not very large. It also implies that small improvements in productivity will have large effects on long-run output, but these improvements will require increases in both the quantity and the quality of schooling.

Human Capital Quality

How large are the model-implied differences in the average quality of human capital between rich and poor countries? The conceptual exercise is to determine the differences in human capital between two workers in different countries once the schooling component has been netted out.

The model I discuss implies that the human capital of the average worker in the lowest decile is only 7 percent of the human capital of the average worker in the United States. Part of that difference is driven by differences in schooling, but differences in quality (i.e., differences in h_i^q) are also significant. Using the estimates, I find that

$$\frac{h_P^q}{h_{US}^q} = 0.17,$$

which implies that the quality of human capital is much lower in poor countries. To be precise, the average qualitative component of the human capital of a worker in the bottom 10 percent of the world income distribution is only 17 percent of that of a U.S. worker. Thus, not only do U.S. workers have significantly more schooling, but they also have better schooling (and OJT). In addition, the U.S. workforce is older and, hence, has more experience (OJT) and this contributes to the quality differentials.

The Importance of Early Childhood and On-the-Job Training

It is instructive to decompose the differences in average human capital per worker into three components: early childhood, schooling, and OJT. The model implies that, even at age 6, there are substantial differences between the human capital of the average child in rich and poor countries. Table 2 presents the values of human capital at age 6 (h_E) and aggregate human capital per worker (\bar{h}^e) for three deciles relative to those of the United States. The values imply that only 8 percent of the human capital for the average worker in a rich country is acquired before 6 years of age, while the contribution of early childhood human capital is 44 percent for the average worker in a poor country. This large difference is driven by two factors. First, differences in health and nutrition imply differences in human capital at age 6. Second, in rich countries workers tend to be older and acquire significantly more human capital over their lifetimes, whereas in poor countries the average worker is much younger—and, hence, has not had the time to accumulate human capital—and invests less in schooling and OJT.

According to the model, OJT is an important source of human capital. In rich countries it accounts for 43 percent of all the available human capital and even in poor countries it represents 32 percent of the total. The results suggest that policies that influence OJT can have a potentially large impact of output per worker.

DEMOGRAPHICS AND DEVELOPMENT

The evidence described previously shows that rich and poor countries differ in terms of their demographic structure, and this plays an important role in terms of estimating the level

of human capital per worker. The reason is simple: Countries with high fertility rates are also countries in which the labor force is relatively young. This, in turn, implies that the amount of human capital per worker is small since human capital increases over the lifetime as a result of investment in OJT.

A Simple Demographic Change Experiment

One could use the model to ask the following question: What would happen to the level of output per worker in the poorest country (lowest decile) if that country had the demographic parameters (e.g., the same fertility and mortality rates) of the United States? To answer this question, I use the model to perform a theoretical exercise and calculate the estimated productivity of the average country in the lowest decile (63 percent of the U.S. productivity) if that country had the U.S. demographic variables. To be precise, I estimate the impact on output per worker if the average woman had 1.7 children instead of 5.2 and the life expectancy at age 5 was increased from 56 to 80 years.

I find that this shift in demographic variables would result in a 53 percent increase in output per worker. According to the model, this increase in output is accompanied by a 26 percent increase in the level of schooling (from 2.83 to 3.59 years of schooling for the average worker). In this experiment, demographic change drives both schooling and output. Thus, the model is consistent with the view that changes in fertility can have large effects on output. It is important to emphasize that these quantitative estimates reflect long-run changes. The reason is that the changes in demographic variables assume that the level of human capital has fully adjusted to its new steady-state level. Given the generational structure, this adjustment can take a long time.

Endogenous Fertility and Mortality

Because demographic variables play such a large role in output, it is of interest to “force” the model to account for the fertility choices made by individuals in poor and rich countries. Following the work of Barro and Becker (1989), Manuelli and Seshadri (2009) extend this human capital model and explicitly account for the cost of raising children and the fact that, in poor countries, children are also a source of labor and income.

To be precise, the basic model described previously must be enriched with fertility and health investment choices. Individuals are assumed to choose the number of children, f , along the lines of Barro and Becker (1989) and to care about the welfare of their descendants. There is a technology to “produce” life expectancy, $T(g)$, which uses market goods, g . This is a simple way to capture the potential life expectancy effect of resources devoted to sanitation, health care infrastructure, and other investments that influence health.

Formally, the utility function of a parent who has h units of human capital and a bequest equal to b at age I is given by

$$W^P(h, b, g) = \int_I^{T(g)} e^{-\rho(a-I)} u(c(a)) da + e^{-\alpha_0 + \alpha_1 f}$$

$$\int_0^I e^{-\rho(a+B-I)} u(c_k(a)) da + e^{-\alpha_0 + \alpha_1 f} e^{-\rho B} W^k(h_k(I), b_k, g_k).$$

Thus, the contribution to the parent's utility of an a -year-old child still dependent on him is $e^{-a_0 + a_1 f} e^{-\rho(a+B-I)} u(c_k(a))$, since at that time the parent is $a + B$ years old. In this formulation, $e^{-a_0 + a_1 f}$ captures the degree of altruism. If $a_0 = 0$, and $a_1 = 1$, this is a standard infinitely lived agent model. Positive values of a_0 and values of a_1 less than 1 capture the degree of imperfect altruism. The term $W^k(h_k(I), b_k, g_k)$ is the utility of a child at the time he becomes independent.

The model is completed by adding (i) a human capital accumulation technology, (ii) an aggregate production function as described earlier, and (iii) a technology to produce life expectancy given by

$$T(g) = \bar{T}(1 - e^{-\mu g}), \quad \mu > 0.$$

This technology implies that, in the model, the maximum life span (for the average individual) is \bar{T} . I assume that the instantaneous utility function is

$$u(c) = \frac{c^{1-\theta}}{1-\theta}, \quad 0 < \theta < 1.$$

It is necessary to choose parameter values for all the functions to draw quantitative implications from this model. Manuelli and Seshadri (2009) discuss this in detail, but the strategy is very similar to the one used to account for cross-country differences in income: Choose parameter values such that the model reproduces the appropriate moments for the United States around 2000 (which is considered a normal year).

What is the connection between productivity, z , and health variables? The model implies that a 25 percent increase in the level of TFP (z) in a poor country (the bottom decile) would result in a tenfold increase in its output per worker and would position this country in the middle of the world income distribution. Of course, the direct effect of productivity is small, but according to the model this triggers the following changes: an average increase in schooling of almost six additional years; a 50 percent reduction in the number of children per woman; and a 40 percent increase in life expectancy. Improvements in productivity are the drivers in this exercise of increases in schooling, increases in life expectancy, and decreases in fertility. All three variables respond to the improved economic conditions.

From the perspective of the individuals in the model, it is the higher return to human capital accumulation (higher wages) that leads them to make changes in their economic and demographic choices. The mechanism through which this occurs parallels Becker's (1993) quantity-quality trade-off. An increase in productivity results in an increase in the wage rate and, hence, an increase in the return to human capital. Faced with this new set of prices, families choose to invest more in the human capital of their children and to have fewer children. The investment in human capital takes the form of more (and better) schooling and more (and better) health care.

DISEASE AND DEVELOPMENT

Health is another dimension of human capital. In this section, I modify the model to account for the influence of a disease environment on output per worker. I concentrate on two diseases that have large impacts on sub-Saharan Africa: AIDS and malaria.

Consider the case of AIDS first. The disease environment can be described by two parameters: the infection rate and life expectancy conditional on being infected. Both events can be modeled as the occurrence of a Poisson process. Thus, healthy individuals understand when they are making their human capital investment decisions that they might become infected with AIDS and, hence, that their life expectancy could be lower in that event. In this specification, a lower life expectancy is equivalent to discounting the future more heavily.

Let the maximum life span be denoted by \bar{T} .⁸ Then, if the probability of death over a short interval of time dt is λdt and using N to denote the length of life in years, I assume that

$$P(N \leq a) = \frac{1 - e^{-\lambda a}}{1 - e^{-\lambda \bar{T}}}, \quad \text{for } a \leq \bar{T}.$$

This implies that the life expectancy at age a is

$$E[N|a] = \frac{1 - e^{-\lambda(\bar{T}-a)}}{\lambda},$$

which, given our choice of \bar{T} , is close to $1/\lambda$ for a newborn.

To simplify the presentation, let $\hat{r}(x) = r + x$ and, as before,

$$m(t; \hat{r}(x)) = 1 - e^{-(\hat{r}(x) + \delta_h)(R-t)}.$$

To describe the impact of a disease environment, consider the types of risks faced by a person who could become infected with AIDS. First, a healthy individual can become infected. Second, conditional on infection, life expectancy is lower. The following policies will have an impact on the incentives for an individual to accumulate human capital: reducing the probability of infection (e.g., increased use of protection during sexual intercourse) or increasing the availability and effectiveness of antiretroviral drugs, thereby resulting in higher life expectancy conditional on infection.

What is the mechanism through which a higher probability of death affects investment in human capital? To explore the possible answers to this question, consider how the instantaneous probability of death affects the present discounted value of any income stream, $y(t) = y$. If discounted at the rate r , the present value—over an infinite horizon—is simply y/r .

Now consider the case in which income is $y > 0$ while the individual is alive and zero thereafter. In this case, the expected present discounted value of income is

$$\int_0^\infty \left(\int_0^n e^{-rt} y dt \right) \frac{\lambda e^{-\lambda n}}{1 - e^{-\lambda \bar{T}}} dn = \frac{y}{r + \lambda} \left[r - \frac{\lambda e^{-\lambda \bar{T}}}{1 - e^{-\lambda \bar{T}}} \right] (1 - e^{-r \bar{T}}),$$

Table 3
Lower AIDS Transmission Rate (%)

Country	Δy	Δs	$\Delta(\bar{h}^e/s)$
Cameroon	9.2	1.8	7.7
Ghana	4.0	1.2	2.9
Malawi	19.5	13.6	3.4
Zimbabwe	24.3	8.6	15.1

which is decreasing in λ . Thus, mortality risk has an effect very similar to increasing the discount rate used by individuals. Since a higher discount requires a higher payoff to induce individuals to invest, the natural response is to invest less.

In the case of malaria—the other disease environment considered—the condition has a relatively small impact on adult life expectancy⁹ but a significant effect on the infected individual's ability to learn and to use human capital because of the higher morbidity associated with malaria. In this case, I use estimates of the effect on income earned by those with malaria to calibrate the learning ability parameter, z_h .¹⁰

I have previously used the human capital accumulation model to study the impact of some changes in the disease environments associated with both AIDS and malaria for some sub-Saharan African countries (for details, see Manuelli, 2011). Here I describe the effects for Cameroon, Ghana, Malawi, and Zimbabwe.

Table 3 shows the percentage change in output per worker, Δy , years of schooling, Δs , and the level of human capital per year of schooling (a measure of quality), $\Delta(\bar{h}^e/s)$, associated with decreasing the rate of transmission of HIV/AIDS to one-half of the current value for each country.

In countries where the AIDS epidemic is relatively mild (e.g., Ghana), the gains in output are small (about 4 percent). However, in countries such as Malawi and Zimbabwe, the predicted increase in output exceeds 19 percent. Depending on the country, the model implies that the fraction of the increase in output accounted for by increases in schooling (the quantity variable) or increases in the level of human capital per year of schooling (the quality variable) varies. For example, in Malawi most of the predicted increase appears to be associated with increased years of schooling, while in Zimbabwe the largest component is the increase in quality.

Table 4 shows the results of a first attempt to evaluate the effect of increases in life expectancy for individuals infected with the AIDS virus (e.g., through increased availability of anti-retroviral drugs). I study the impact of doubling the life expectancy of an infected individual. This implies that infected individuals have a higher incentive to accumulate human capital, just as healthy individuals do, because the cost of infection (which is the probability of death) is now lower.

As expected, the impact is large in Zimbabwe and Malawi, moderate in Cameroon (which has intermediate levels of AIDS and malaria), and small in Ghana. As before, there is hetero-

Table 4**Higher Life Expectancy: AIDS (%)**

Country	Δy	Δs	$\Delta(\bar{h}^e/s)$
Cameroon	10.8	1.9	7.9
Ghana	4.5	1.3	2.8
Malawi	23.5	16.1	0.8
Zimbabwe	32.5	9.5	18.1

Table 5**Lower Incidence of Malaria (%)**

Country	Δy	Δs	$\Delta(\bar{h}^e/s)$
Cameroon	7.7	2.4	4.1
Ghana	13.3	4.6	2.7
Malawi	9.4	8.0	0.0
Zimbabwe	1.4	1.1	0.0

Table 6**Combined Effect of Interventions (% change)**

Country	Δy	Δs	$\Delta(\bar{h}^e/s)$
Cameroon	23.9	4.0	18.5
Ghana	20.6	5.6	13.0
Malawi	45.7	24.4	10.9
Zimbabwe	47.9	11.7	32.0

geneity in the response of quantity (schooling) or quality (human capital per year of schooling) which reflects the differences in productivity.

Table 5 shows the results of reducing the current malaria incidence by 50 percent for each country. The effect on output per worker, schooling, and the quality of human capital is significant in an environment with a high rate of malaria such as Ghana but small in Zimbabwe.

Finally, Table 6 shows the combined impact of all three interventions: halving the rates of transmission of AIDS and the incidence of malaria and doubling the life expectancy conditional on a worker being infected with the AIDS virus. The effects are very large and result in increased output per worker ranging from 20 percent to almost 50 percent. The changes in the disease environment induce individuals to increase their years of schooling and the quality of their education and OJT.

Improvements in disease environments hold the promise of large increases in output for many sub-Saharan African countries. According to the model, such improvements would increase the demand for schooling and individuals would choose higher-quality education and jobs that allow them to better develop their skills.

CONCLUSION

The quantitative importance of human capital in understanding cross-country income differences has been and will continue to be a hotly debated issue. In this article, I show that a standard human capital framework implies large cross-country differences in the stocks of human capital driven by relatively small differences in TFP. The results suggest that (i) human capital has a central role in determining the wealth of nations and (ii) the quality of human capital varies systematically with the level of development. The model successfully captures the large variation in levels of schooling across countries, which implies that differences in the quality of human capital account for a large fraction of the cross-country differences in output. The typical individual in a poor country not only chooses to acquire fewer years of schooling but also acquires less human capital per year of schooling.

For very poor countries—in this article, some sub-Saharan African countries—the prevalence of AIDS and malaria is an additional barrier to growth. The model suggests that improvements in these dimensions will be accompanied by increases in investment in human capital.

The policy implications of this framework are clear: Policies that achieve small changes in increasing TFP and improving disease environments can have large long-run effects on output per capita. The effects are not primarily due to the direct impact of higher TFP. Rather, their indirect effects—those on the quantity and quality of schooling chosen by individuals—account for most of the impact. The model suggests there are large payoffs to understanding which factors explain productivity differences since they play a central role in explaining development.

One important caveat is in order: The effects described in this article refer to the long-run impact on the relevant variables, and they take place over several generations. For some reasonable parameterizations, it can take more than 40 years for an economy to converge to the new steady state. Moreover, some preliminary work suggests that the dynamic adjustment path is not monotone. To be precise, it is possible for output to increase in response to an increase in productivity because some individuals will choose to invest more in human capital, and this can potentially decrease measured output.¹¹ ■

APPENDIX

An individual with human capital h and age a who will retire at $R \leq T$, where T is lifespan, solves the following problem:

$$V(h, a) = \max_{h(t), n(t), x(t)} \int_a^R e^{-r(t-a)} (1-\tau) [wh(t)(1-n(t)) - p_w x(a)] da,$$

subject to

$$\dot{h}(t) = z_h (n(t)h(t))^{\gamma_1} x(t)^{\gamma_2} - \delta_h h(t), \quad t \in [a, R],$$

and I look for solutions where $n(t) \in [0, 1]$.

The following proposition describes properties of the function $V(h, a)$.

Proposition 1

The function $V(h, a)$ is given by

$$(A.1) \quad V(h, a) = (1-\tau) w \left\{ \frac{m(a)}{r+\delta_h} h + \frac{1-\gamma}{\gamma_1} w^{\gamma_2} C^{1/(1-\gamma)} \int_a^R e^{-r(t-a)} m(t)^{1/(1-\gamma)} dt \right\},$$

where

$$C = \frac{z_h \gamma_1}{r+\delta_h} \left(\frac{\gamma_2}{p_w \gamma_1} \right)^{\gamma_2}$$

and

$$m(a) = 1 - e^{-(r+\delta_h)(R-a)}.$$

Proof

The Hamilton-Jacobi-Bellman equation corresponding to that problem is

$$(A.2) \quad rF(h, a) = \max_{n, x} (1-\tau) [wh(1-n) - p_w x] + F_h(h, a) [z_h (nh)^{\gamma_1} x^{\gamma_2} - \delta_h h] + F_a(h, a)$$

with boundary condition

$$F(h, R) = 0.$$

A direct calculation shows that equation (A.1) satisfies equation (A.2) and the boundary condition.

It is easy to show that the optimal solution has the property that

$$(A.3) \quad n(a)h(a) = w^{\gamma_2/(1-\gamma)} C^{1/(1-\gamma)} m(a)^{1/(1-\gamma)},$$

and this implies that effective time invested in OJT declines quickly with tenure at the same time the level of human capital increases. It also shows that when the wage rate is higher, individuals are more willing to invest in training.

NOTES

- ¹ There are small differences across countries in the average return to schooling, but the estimates that follow are robust to those differences. For some issues measuring this return, see Card (2001).
- ² See Klenow and Rodríguez-Clare (1997) for a similar view and Caselli (2005) for a good survey of alternative measures of the contributions of TFP and human capital to growth.
- ³ For a related model, see Erosa, Koreshkova, and Restuccia (2010).
- ⁴ This is simply a variant of Ben-Porath (1967). On the impact of school quality—here proxied by x_s —on the returns to education, see Card and Kruger (1992); for evidence in a relatively poor country, see Case and Yogo (1999). For a survey, see Hanushek (2006).
- ⁵ This assumption effectively accepts the notion that capital market imperfections are not critical. Even though it is a simplifying assumption, this seems the natural first step toward building a good model of human capital accumulation.
- ⁶ This notion of wage is not equivalent to measured hourly wages. To be specific, the hourly wage of a worker who has human capital h is wh . Thus, in this view, wage differences across workers in the same environment are driven by differences in human capital.
- ⁷ The elasticity that can be inferred from Table 2 is much higher, around 9.4. The reason is that those values reflect changes in TFP and demographic variables.
- ⁸ As this parameter is measured in years, it seems that a reasonable estimate is $\bar{T} = 120$.
- ⁹ It has a significant impact on child mortality; but in this model I focus on individuals who reach school age, and at this point the mortality impact of malaria is lower.
- ¹⁰ See the details in Manuelli (2011).
- ¹¹ Of course, if investment in human capital through schooling and OJT were included in the national income accounts, output would not decrease. However, these forms of investment are unmeasured.

REFERENCES

- Barro, Robert J. and Becker, Gary S. "Fertility Choice in a Model of Economic Growth." *Econometrica*, March 1989, 57(2), pp. 481-501.
- Barro, Robert J. and Lee, Jong-Wha. "A New Data Set of Educational Attainment in the World, 1950-2010." NBER Working Paper No. 15902, National Bureau of Economic Research, April 2010; <http://www.nber.org/papers/w15902.pdf>.
- Becker, Gary S. *Human Capital: A Theoretical and Empirical Analysis, with Special Reference to Education*. Third Edition. Chicago: University of Chicago Press, 1993.
- Ben-Porath, Yoram. "The Production of Human Capital and the Life Cycle of Earnings." *Journal of Political Economy*, August 1967, 75(4 Part 1), pp. 352-65.
- Bils, Mark, and Klenow, Peter J. "Explaining Differences in Schooling Across Countries." Working paper, University of Chicago, January 2000.
- Bils, Mark and Klenow, Peter J. "Does Schooling Cause Growth?" *American Economic Review*, December 2000, 90(5), pp. 1160-83.
- Card, David. "Estimating the Return to Schooling: Progress on Some Persistent Econometric Problems." *Econometrica*, September 2001, 69(5), pp. 1127-60.
- Card, David and Krueger, Alan B. "Does School Quality Matter? Returns to Education and the Characteristics of Public Schools in the United States." *Journal of Political Economy*, February 1992, 100(1), pp. 1-40.
- Case, Anne and Yogo, Motohiro. "Does School Quality Matter? Returns to Education and the Characteristics of Schools in South Africa." NBER Working Paper No. 7399, National Bureau of Economic Research, October 1999; <http://www.nber.org/papers/w7399.pdf>.

Manuelli

- Caselli, Francesco. "Accounting for Cross-Country Income Differences," in Philippe Aghion and Steven N. Durlauf, eds., *Handbook of Economic Growth*. Volume IA. Chap. 9. Amsterdam: Elsevier BV, 2005, pp. 679-741.
- Erosa, Andrés; Koreshkova, Tatyana and Restuccia, Diego. "How Important Is Human Capital? A Quantitative Theory Assessment of World Income Inequality." *Review of Economic Studies*, 2010, 77(4), pp. 1421-49.
- Hall, Robert E. and Jones, Charles I. "Why Do Some Countries Produce So Much More Output per Worker Than Others?" *Quarterly Journal of Economics*, February 1999, 114(1), pp. 83-116.
- Hanushek, Eric A. "School Resources," in Eric A. Hanushek and Finis Welch, eds., *Handbook of the Economics of Education*. Volume 2. Chap. 14. Amsterdam: Elsevier BV, 2006, pp. 865-908.
- Klenow, Peter J. and Rodríguez-Clare, Andres. "The Neoclassical Revival in Growth Economics: Has It Gone Too Far?" in Ben S. Bernanke and Julio J. Rotemberg, eds., *NBER Macroeconomics Annual 1997*. Volume 12. Cambridge, MA: 1997, pp. 73-114.
- Manuelli, Rodolfo E. "Disease and Development: The Case of Human Capital." Working Paper No. 2011-008, Human Capital and Economic Opportunity Global Working Group, November 2011.
- Manuelli, Rodolfo E. and Seshadri, Ananth. "Explaining International Fertility Differences." *Quarterly Journal of Economics*, May 2009, 124(2), pp. 771-807.
- Manuelli, Rodolfo E. and Seshadri, Ananth. "Human Capital and the Wealth of Nations." *American Economic Review*, September 2014, 104(9), pp. 2736-62.
- Parente, Stephen L. and Prescott, Edward C. *Barriers to Riches*. Cambridge, MA: MIT Press, 2000.
- Psacharopoulos, George and Patrinos, Harry A. "Returns to Investment in Education: A Further Update." *Education Economics*, August 2004, 12(2), pp: 111-34.
- United Nations. *World Population Prospects: The 2012 Revision*. New York: United Nations, Department of Economic and Social Affairs, Population Division, 2013.

Monetary Policy in Small Open Economies: The Role of Exchange Rate Rules

Ana Maria Santacreu

Understanding the costs and benefits of alternative monetary policy rules is important for economic welfare. Within the context of a small open economy model and building on the work of Mihov and Santacreu (2013), the author analyzes the economic implications of two monetary policy rules. The first is a rule in which the central bank uses the nominal exchange rate as its policy instrument and adjusts the rate whenever there are changes in the economic environment. The second is a standard interest rate rule in which the central bank adjusts the short-term nominal interest rate to changes in the economic environment. The main finding of the analysis is that, if the uncovered interest parity condition that establishes a tight link between the interest rate differential in two countries and the expected rate of depreciation of their currencies does not hold, the exchange rate rule outperforms the standard interest rate rule in lowering the volatility of key economic variables. There are two main reasons for this: First, the actual implementation of the exchange rate rule avoids the overshooting effect on exchange rates characteristic of an interest rate rule. And second, the risk premium that generates deviations from the uncovered interest parity condition is smaller and less volatile under an exchange rate rule. (JEL E52, E58, F41)

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The objective, either explicit or implicit, for most central banks is to keep inflation low and stable while avoiding large fluctuations in real economic variables (i.e., output and unemployment).¹ To achieve their objective, central banks use an instrument, typically the nominal interest rate, that is adjusted when there are deviations of inflation from an explicit or implicit target or deviations of output from its potential (i.e., significant deviations in the output gap). Most central banks adjust their interest rate in a manner consistent with the so-called Taylor rule—an interest rate rule (IRR) that specifies by how much the monetary authority increases (decreases) the short-term nominal interest rate when inflation is above (below) the target or the output gap is positive (negative).²

In small open economies, however, the exchange rate is an important element of the transmission of monetary policy (Svensson, 2000). Central banks in such economies generally

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prefer to maintain tight control over the exchange rate. Several authors have analyzed the performance of monetary rules that explicitly take into account the exchange rate in the context of general equilibrium models. In particular, two exchange rate situations have been analyzed: (i) flexible exchange rates in which the monetary authority follows an extended IRR that reacts to deviations of inflation, output, and the exchange rate (De Paoli, 2009) or (ii) fixed exchange rates in which the central bank pegs the exchange rate to the currency of another country and commits to defending such a peg by losing its ability to control the nominal interest rate (Schmitt-Grohé and Uribe, 2011). The United States, Canada, and Japan, for instance, follow a flexible exchange rate regime. Hong Kong, Denmark, and Bulgaria follow a fixed exchange rate regime.

There is a third possibility that has not been analyzed extensively in the context of a general equilibrium model. The central bank could use the exchange rate as an instrument in the same way it uses the interest rate in the IRR—that is, by adjusting the exchange rate to fluctuations in economic conditions. This is known as an exchange rate rule (ERR) and is the policy followed by the Monetary Authority of Singapore (MAS) since 1981. Indeed, 98 percent of the assets held on the MAS balance sheet are foreign assets. Therefore, in contrast to other small open economies in which the central bank intervenes mainly in the domestic bond market to conduct monetary policy while still paying attention to fluctuations in the nominal exchange rate (as in New Zealand, Australia, and Canada), the MAS intervenes mainly in the foreign exchange market to conduct monetary policy. (This scenario differs from situation (i) mentioned earlier.) Thus, their instrument is the nominal effective exchange rate, which is allowed to fluctuate whenever there are changes in economic conditions. (This scenario differs from situation (ii) mentioned earlier.)

In a recent article, Mihov and Santacreu (2013) attempt to fill this gap in the literature by analyzing a small open economy model of monetary policy to compare the implications of two types of rules for economic volatility. First, they examine a model in which the central bank uses the short-term nominal interest rate as the instrument and allows the exchange rate to adjust from the decisions of economic agents (IRR). Then, they study a model in which the central bank uses the exchange rate as the instrument and allows the interest rate to adjust from the decisions of economic agents (ERR). They ask the following question: Under what conditions can a central bank achieve lower economic volatility by using an ERR rather than an IRR?

Mihov and Santacreu (2013) argue that the costs and benefits of an IRR versus those of an ERR depend on two factors: the actual implementation of the policy and whether the uncovered interest parity (UIP) condition holds. First, the actual implementation of the rule is important. While the central bank technically can replicate any IRR by moving the exchange rate today and announcing depreciation consistent with UIP, this is not how the rule operates.

In Mihov and Santacreu (2013), the exchange rate today is predetermined and the central bank announces the depreciation rate from time t to $t + 1$. This implies, for example, that the model may not feature the standard overshooting result as the currency rate both today and at $t + 1$ are determined by the monetary authority. However, they find this feature is insufficient in generating significant differences between the two rules. Therefore, the only way the

new model can provide interesting dynamics is by incorporating a failure of UIP. UIP predicts that currencies with high interest rates will depreciate relative to those with low interest rates. That is, arbitrage should ensure that the following two investment strategies are equivalent: An investor either buys a domestic asset at the current domestic interest rate and collects the proceedings tomorrow or exchanges domestic currency for foreign currency at the current exchange rate to invest in an identical foreign asset that pays the interest rate of the foreign country and tomorrow exchanges the foreign currency back to domestic currency. This strategy implies that if the domestic interest rate is higher than the foreign interest rate, one should expect the domestic currency to depreciate between today and tomorrow.

Alvarez, Atkeson, and Kehoe (2007) argue that in large part the impact of monetary policy on the economy proceeds through conditional variances of macroeconomic variables rather than conditional means. In terms of the UIP condition, their article implies that the interest parity condition has a time-varying risk premium. Interest in time-varying risk premiums has been growing in recent years. In the context of the interest parity condition, Verdelhan (2010) shows how consumption models with external habit formation can generate a countercyclical risk premium that matches key stylized facts quite successfully. Mihov and Santacreu (2013) adopt a similar approach by allowing external habit formation in consumption.

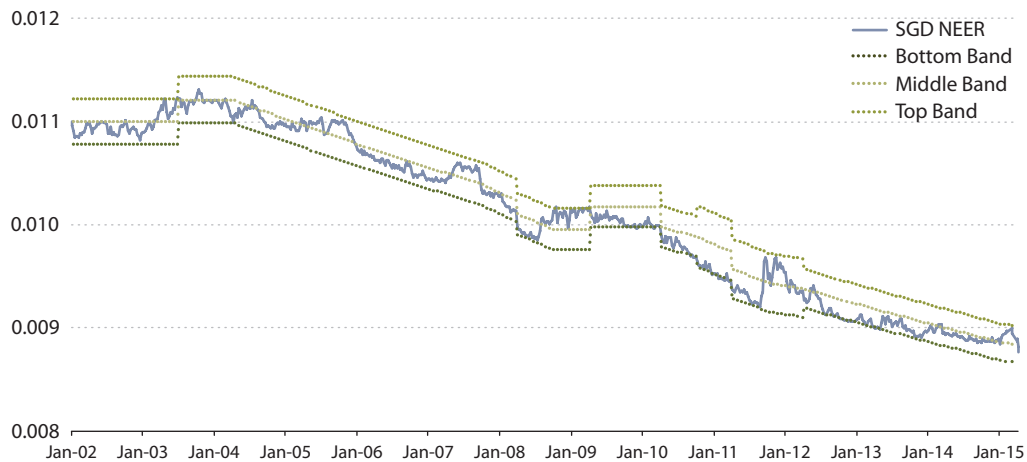
In a production economy, Mihov and Santacreu (2013) find that an ERR achieves lower volatility of both nominal and real variables. Contrary to a fixed exchange rate scenario in which the central bank achieves lower volatility of nominal variables at the expense of increasing the volatility of the real variables (Schmitt-Grohé and Uribe, 2011), an ERR can stabilize both because it is an intermediate exchange rate regime. The reasons are twofold: First, the actual implementation of the policy avoids the overshooting effect of an IRR. Second, an ERR reduces the mean and the volatility of the risk premium that causes deviations from UIP.

The article proceeds as follows. First, I describe how an ERR operates and use the case of Singapore to illustrate it. Then, I present an endowment economy that features deviations from UIP through the existence of a risk premium. I show that the risk premium responsible for these deviations depends on the particular policy rule the central bank follows (IRR versus ERR) and the parameters of the monetary policy rule. In an endowment economy, these deviations affect only nominal variables. To capture the effect of alternative rules on both nominal and real variables, I then describe a small open production economy in which consumption and output are both endogenous and report the quantitative implications of the model.

EXCHANGE RATE RULES: SINGAPORE

In this section, I describe Singapore's monetary policy to illustrate how an ERR works. According to the MAS Act, the main objective of monetary policy in Singapore is "to ensure low inflation as a sound basis for sustained economic growth" (Monetary Authority of Singapore). To do that, since 1981,

The MAS manages the Singapore dollar (S\$) exchange rate against a trade-weighted basket of currencies of Singapore's major trading partners and competitors. The composition of this basket is reviewed and revised periodically to take into account changes in Singapore's

Figure 1**Singapore Dollar Nominal Effective Exchange Rate**

NOTE: Here, the Singapore dollar (SGD) nominal effective exchange rate (NEER) is defined as the inverse of the usual NEER and in terms of trade-weighted trading partners' currencies per the Singapore dollar. Thus, the decrease in the figure means an appreciation of the Singapore dollar currency. The bottom, middle, and top band indexes are estimated by Citigroup, based on MAS monetary policy statements.

SOURCE: Calculations based on: Citi Research, SGD NEER Indices, Bloomberg Finance L.P.; accessed April 2015.

trade patterns. This trade-weighted exchange rate is maintained broadly within an undisclosed target band, and is allowed to appreciate or depreciate depending on factors such as the level of world inflation and domestic price pressures. MAS may also intervene in the foreign exchange market to prevent excessive fluctuations in the S\$ exchange rate.

In the context of Singapore's open capital account, the choice of the exchange rate as the focus of monetary policy would necessarily imply that domestic interest rates and money supply are endogenous. As such, MAS's money market operations are conducted mainly to ensure that sufficient liquidity is present in the banking system to meet banks' demand for reserve and settlement balances. (Monetary Authority of Singapore)

Specifically, the MAS announces a path of appreciation or depreciation of its currency based on the expected economic conditions. Figure 1 shows Singapore's nominal exchange rate with respect to a basket of currencies since January 2002. As the downward trend reveals, the Singapore dollar has been appreciating over time, which reflects Singapore's rapid economic development during this time. (The definition of the exchange rate in the figure is such that a decrease implies an appreciation of the Singapore dollar.) In the short run, the exchange rate fluctuates. To avoid misalignment and deviations from the fundamentals, the MAS intervenes in the foreign exchange market to keep the value of the exchange rate within a specified policy band. The monetary authority may change the slope of the band when changes in the economic environment call for it. As Figure 1 shows, the MAS has changed the slope of appreciation of

Table 1**Reaction Function**

Constant (α)	Inflation ($\widehat{\phi}_\pi$)	Output gap ($\widehat{\phi}_y$)	Lagged appreciation (ρ)
-0.379	0.288**	0.276**	0.744***
(0.291)	(0.120)	(0.130)	(0.052)

NOTE: Standard errors are shown in parentheses. ** and *** denote significance at the 5 percent and 1 percent levels, respectively.

SOURCE: Mihov (2013). Used with permission.

the instrument several times. The most recent intervention was in January 2015, when the MAS slowed the rate of appreciation of the Singapore dollar.³

Several authors (see, for example, Parrado, 2004) have estimated a reaction function for changes in the monetary policy instrument as proxied by the change in the nominal exchange rate. Traditional empirical reaction functions have used the nominal interest rate as the instrument. Monetary policy in Singapore is unique in that it uses the nominal exchange rate to achieve low inflation and sustained growth. In particular, assume (i) that the monetary authority has a target for the change in the nominal exchange rate Δe_t^* and (ii) that it adjusts the target based on deviations of inflation from a prespecified target and deviations of output from its potential level as follows:

$$\Delta e_t^* = \Delta \bar{e} - \phi_\pi (\pi_t - \pi^*) - \phi_y (y_t - y^*),$$

where $\Delta \bar{e}$ is the long-run equilibrium change in the nominal exchange rate consistent with long-run purchasing power parity, π_t is the inflation rate at time t , π^* is a target for inflation, y_t is the level of output, and y^* is the potential level of output the economy would produce if all the factors of production were fully employed (i.e., $y_t - y^*$ is the output gap). Consistent with the definition of the nominal effective exchange rate in Figure 1, an increase in the nominal exchange rate in the equation represents a depreciation of the Singapore dollar. I follow this convention throughout the article.

To capture some degree of smoothing in the adjustment of the nominal exchange rate to its target level,

$$\Delta e_t = (1 - \rho_e) \Delta e_t^* + \rho_e \Delta e_{t-1},$$

where $\rho_e \in [0, 1]$ is the degree of exchange rate smoothing.

Combining the two previous expressions yields the following equation:

$$\Delta e_t = \alpha - \widehat{\phi}_\pi (\pi_t - \pi^*) - \widehat{\phi}_y (y_t - y^*) + \rho \Delta e_{t-1},$$

where α is a constant, $\widehat{\phi}_\pi = \phi_\pi(1-\rho_e)$, and $\widehat{\phi}_y = \phi_y(1-\rho_e)$. Table 1 reports the results from the estimation of the previous expression.⁴

Table 1 shows that the Singapore dollar appreciates when inflation increases or the output gap widens. In particular, a 1 percent increase in inflation implies a 0.288 percent appreciation in the Singapore dollar. Similarly, a 1 percent increase in the output gap implies a 0.276 percent appreciation in the Singapore dollar. The estimation also shows some degree of exchange rate smoothing, with an estimated smoothing parameter of 0.744.

MONETARY POLICY AND THE UNCOVERED INTEREST PARITY CONDITION: AN ENDOWMENT ECONOMY

Next, I present a model that captures deviations from UIP by introducing an endogenous risk premium on foreign-denominated assets. I start with an endowment economy so that I can derive an analytical expression for the risk premium. The economy is a small open economy in which there is a representative consumer who maximizes a utility function that features external habit in consumption. Consumption follows an exogenous process, and there are complete international markets. Inflation is determined by a central bank that uses either the nominal interest rate (the IRR) or the exchange rate (the ERR) as its instrument. I assume that, in the rest of the world, the central bank follows an IRR, since it behaves as a closed economy and is not as strongly affected by fluctuations in the nominal exchange rate as the small open economy.

After deriving an analytical solution for the risk premium under both monetary policy rules (an IRR and an ERR), I show that the risk premium responsible for deviations from UIP depends on the particular monetary rule followed by the central bank and the parameters of the rule—that is, on the magnitude of the central bank’s reaction to fluctuations in inflation and the output gap.

Theory

Standard asset-pricing models assume that the UIP condition holds. That is, the models predict that high interest rate currencies will depreciate relative to low interest rate currencies to satisfy an arbitrage condition. However, for many currency pairs and time periods, the opposite seems to occur (Fama, 1984). In the literature, the inability of asset-pricing models to reproduce the empirical evidence is referred to as the UIP puzzle. The UIP evidence is related to short-term interest rates and currency depreciation rates. Because monetary policy influences short-term interest rates in the case of an IRR or nominal exchange rates in the case of an ERR, the UIP puzzle can be formulated in terms of monetary policy (Backus et al., 2010). A traditional open economy model cannot replicate the forward premium anomaly as it typically assumes that UIP holds. When investors are assumed to be risk neutral, any cross-country differences in interest rates are associated with offsetting movements in expected depreciation. Various approaches in the literature to account for the forward premium anomaly include assuming that markets are incomplete (Benigno, 2009) and modeling the deviations through

a risk premium that generates a wedge between the interest rate differential and the expected exchange rate depreciation (Alvarez, Atkeson, and Kehoe, 2009; Backus et al., 2010; Benigno, Benigno, and Nisticò, 2013; and Verdelhan, 2010, among others). The risk premium interpretation of the UIP puzzle asserts that high interest rate currencies pay positive risk premiums.

Therefore, one could derive an expression for the risk premium that depends on the monetary policy instrument and ask the following question: What monetary policy generates larger fluctuations of the risk premium and therefore larger deviations from the UIP condition? To answer this question, I derive an analytical solution for the foreign exchange risk premium as a function of the monetary rule parameters for both an IRR and an ERR. I follow the procedure described by Backus et al. (2010) for an endowment economy with complete markets but with one modification: Instead of using recursive preferences, I assume there is external habit in the utility function (as in Verdelhan, 2010). External habit formation, also known as “catching up with the Joneses” (Abel, 1990), simplifies the consumer’s optimization problem because the evolution of the stock of habit is taken as exogenous by the consumer.

The following steps are taken to obtain an expression for the risk premium:

Step 1: Preferences. In each country, there is a representative household that maximizes lifetime expected utility. The utility function of the household in the domestic economy is given by

$$(1) \quad E_0 \sum_{t=0}^{\infty} \beta^t U(C_t - hX_t) = \frac{(C_t - hX_t)^{1-\gamma}}{1-\gamma},$$

where γ denotes the coefficient of risk aversion, h is the parameter of habit persistence, X_t is the level of habits defined below, and C_t is consumption.

The evolution of habits follows an AR(1) process with accumulation of habits based on last-period consumption:

$$X_t = \delta X_{t-1} + (1-\delta)C_{t-1},$$

where $\delta \in [0,1]$ captures the degree of habit persistence.

In a model with habit ($h \neq 0$), the consumer cares about deviations of consumption from a certain subsistence level. In this case, the coefficient of relative risk aversion (CRRA) is

$$CRRA_t := \frac{\gamma C_t}{C_t - hX_t}.$$

The CRRA is time varying and countercyclical: In good times, when consumption is far from its subsistence level (i.e., $C_t > hX_t$), the denominator increases and risk aversion decreases. Good times correspond to a positive shock to consumption growth.

Following the literature, assume that the log of consumption follows the AR(1) process

$$(2) \quad \log(C_{t+1}) = \lambda \log(C_t) + \varepsilon_{c,t+1},$$

where $\lambda \in [0,1]$ and $\varepsilon_{c,t+1}$ is an i.i.d. process with zero mean and standard deviation σ_ε .

Step 2: The Stochastic Discount Factor. In this economy, the stochastic discount factor or pricing kernel is determined by the following expression:

$$(3) \quad M_{t,t+1} = \beta \frac{U_c(C_{t+1} - hX_{t+1})}{U_c(C_t - hX_t)} = \beta \left(\frac{C_{t+1} - hX_{t+1}}{C_t - hX_t} \right)^{-\gamma}.$$

Step 3: The Risk-Free Rate. Define the risk-free rate R_t as

$$(4) \quad R_t = \frac{1}{E_t(M_{t,t+1})},$$

where R_t is the gross return on a riskless, one-period discount bond paying off one unit of domestic currency in $t+1$.

The Euler equation of a foreign investor buying a foreign bond with return R_{t+1}^* is

$$(5) \quad E_t(M_{t,t+1}^* R_t^*) = 1.$$

The Euler equation for a domestic investor buying the same foreign bond is

$$(6) \quad E_t \left(M_{t,t+1} R_t^* \frac{Q_{t+1}}{Q_t} \right) = 1,$$

where Q_t is the real exchange rate expressed as the amount of domestic good per unit of foreign good, defined as

$$Q_t = e_t \frac{P_t^*}{P_t},$$

where P_t^* is the price of a basket of foreign goods and P_t that of domestic goods. $M_{t,t+1}$ and $M_{t,t+1}^*$ are the domestic and foreign nominal pricing kernels, respectively.

Step 4: International Risk-Sharing Condition. Households have access to a complete set of contingent securities that are traded internationally—that is, markets are complete. With complete markets, the stochastic discount factor is unique and the following expression holds:

$$(7) \quad \frac{Q_{t+1}}{Q_t} = \frac{M_{t,t+1}^*}{M_{t,t+1}}.$$

We can now define the nominal interest differential $i_t - i_t^*$, where $i_t = \log(R_t)$ and $i_t^* = \log(R_t^*)$, the expected nominal depreciation is $\mathbb{E}_t[de_{t+1}]$, and the exchange rate risk premium is fxp_t in terms of the domestic and foreign nominal pricing kernels, $M_{t,t+1}$ and $M_{t,t+1}^*$, respectively. From the previous expressions we find that the interest rate differential has to equal the difference of the stochastic discount factors in the foreign and domestic economies:

$$i_t - i_t^* = \log(\mathbb{E}_t[M_{t,t+1}^*]) - \log(\mathbb{E}_t[M_{t,t+1}]).$$

With complete markets,

$$\mathbb{E}_t[de_{t+1}] = \mathbb{E}_t[\log(M_{t,t+1}^*)] - \mathbb{E}_t[\log(M_{t,t+1})].$$

Combining the previous two expressions and assuming log-normality of the pricing kernel,⁵

$$(8) \quad i_t - i_t^* = \mathbb{E}_t [de_{t+1}] + fxp_t,$$

with the risk premium defined as

$$(9) \quad fxp_t = \frac{1}{2} \left[\text{Var}_t [\log(M_{t,t+1}^*)] - \text{Var}_t [\log(M_{t,t+1})] \right].$$

The risk premium is equal to half the difference between the conditional variance of the foreign and domestic stochastic discount factors.

The risk premium in equation (9) captures deviations from UIP. In the absence of a risk premium, if the domestic interest rate were higher than the foreign interest rate, the domestic currency would be expected to depreciate over time such that an investor would be indifferent between holding a domestic or a foreign asset. However, with a positive risk premium, it is possible for high interest rate currencies to appreciate over time. This would happen if the investor were risk averse and would demand a positive premium to hold foreign currency.

Step 5: The Monetary Policy Rule. One can now derive an expression for the foreign risk premium when the domestic economy follows one of the two rules: an IRR or an ERR.

Assume that the foreign economy follows an IRR (because it is a large economy and therefore is not as strongly affected by exchange rate fluctuations as the small open economy):

$$(10) \quad i_t^* = \phi_\pi^* \pi_t^* + \phi_c^* c_t^*,$$

where i_t^* is the foreign nominal interest rate, c_t^* is foreign consumption, and π_t^* is foreign inflation.

In the domestic economy, we consider both IRR and ERR, as follows:

(i) IRR

$$(11) \quad i_t = \phi_\pi^{IRR} \pi_t + \phi_c^{IRR} c_t.$$

The central bank increases the interest rate whenever inflation (π_t) and consumption (c_t) increase, with ϕ_π^{IRR} and ϕ_c^{IRR} indicating the magnitude of the adjustment.

(ii) ERR

$$(12) \quad de_t = -\phi_\pi^{ERR} \pi_t - \phi_c^{ERR} c_t.$$

The central bank appreciates the nominal exchange rate whenever inflation (π_t) and consumption (c_t) increase, with ϕ_π^{ERR} and ϕ_c^{ERR} indicating the magnitude of the adjustment.

Step 6: The Risk Premium. To derive an analytical solution for the risk premium, I follow Backus et al. (2010) and use the method of undetermined coefficients; they assume that inflation follows a particular functional form. Then, using the first-order conditions, the international risk-sharing condition, and the expression for the corresponding rule, I obtain an expression for the risk premium that can be expressed as

Table 2**Calibrated Parameters**

Parameter	Description	Value
h	Habit	0.85
δ	Degree habit	0.97
γ	Coefficient of risk aversion	2.50
λ	Persistent shock	0.01
σ_ε	Standard deviation shock	2.50

SOURCE: Modified from Mihov and Santacreu (2013).

$$(13) \quad fxp_t = \kappa_0 - \kappa_1 c_t - \kappa_2 x_t,$$

where x is the log of X and $k_0 > 0$, $k_1 > 0$, and $k_2 > 0$ depend on the particular rule used and the parameters of the monetary policy rule (i.e., how strongly the central bank reacts to deviations of inflation from its target and fluctuations of the output gap).⁶

Note that the risk premium fxp_t is time varying and countercyclical. In good times, when consumption is high, the risk premium decreases. It can also be shown that if $h = 0$, then $k_1 = k_2 = 0$, and there is a constant risk premium.

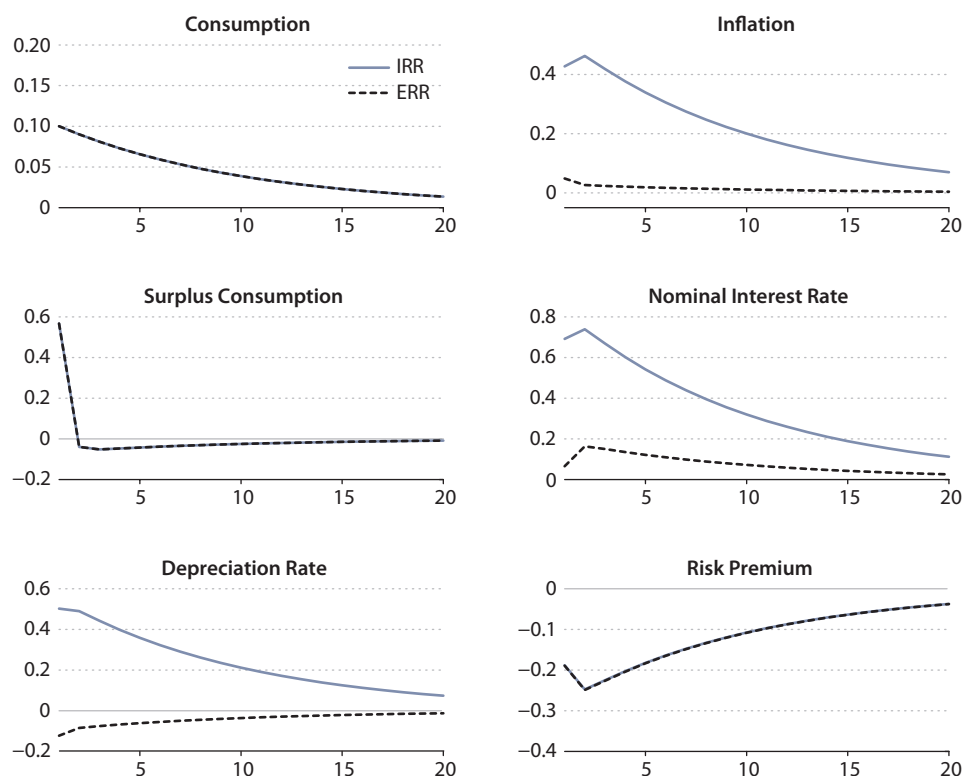
Quantitative Results

Now, I analyze the effect of the two alternative rules on the mean and volatility of the risk premium. Assuming a particular process for consumption growth in equation (2), one can use equation (13) to analyze the effect of the two policy rules on the deviations from UIP. Note that only the nominal variables are affected because consumption follows an exogenous process in this model.

Simulations of the endowment economy described previously show that the mean and the standard deviation of the risk premium differ depending on the particular rule followed by the monetary authority and the parameters of such a rule (i.e., how strongly the central bank reacts to deviations of inflation from its target and fluctuations of the output gap). Table 2 shows the calibrated parameters (see Mihov and Santacreu, 2013).

First, impulse response functions for a 1 percent standard deviation shock to consumption show that both consumption and inflation increase in the case of an IRR (the solid line in Figure 2).⁷ The central bank then increases the interest rate (see equation (11)), and the currency depreciates at $t+1$. If the UIP condition holds, the depreciation is exactly equal to the initial increase in the interest rate. However, because now there is a decrease in the risk premium (through equation (9)), the currency depreciates by less than it would with no risk premium.

In the case of an ERR (the dashed line in Figure 2), after a positive consumption growth the central bank reacts to the increase in both consumption and inflation by appreciating

Figure 2**Impulse Response Function to a Consumption Shock: ERR**

currency until it reaches a new equilibrium. If the UIP condition is satisfied, the interest rate should decrease by exactly the same amount, but the interest rate increases.

As Figure 2 shows, both inflation and the nominal interest rate respond less strongly to a consumption shock when the central bank follows an ERR than when it follows an IRR, which suggests that with an ERR the monetary authority is more successful in stabilizing the nominal variables. One of the main reasons is the actual implementation of the policy. The other is that the risk premium falls by less with an ERR than with an IRR.

The fall in the risk premium after a consumption shock has consequences on the differing effect of the two rules on the nominal variables. To better understand this point, Table 3 reports the mean and variance of the risk premium under each rule (IRR versus ERR) and for different values of the parameters of the reaction function (ϕ_π and ϕ_c). In all cases, the ERR delivers a lower mean and lower volatility in the risk premium. We also observe differences dependent on the magnitude of the monetary authority's reaction to fluctuations in inflation and consumption. These differences are more pronounced when the monetary authority follows an IRR.

Table 3**Risk Premium**

Parameter (ϕ_π, ϕ_ϵ)	IRR			ERR		
	(1.5, 0.5)	(1.05, 0.5)	(1.50, 0.05)	(1.5, 0.5)	(1.05, 0.5)	(1.50, 0.05)
Mean	4.293	10.680	3.985	2.850	2.880	2.915
Standard deviation	0.633	0.644	0.632	0.629	0.629	0.629

Because in this exercise I have modeled an endowment economy assuming the same consumption path under an IRR as under an ERR, the implied differences in the risk premium, although nonnegligible, are small and affect only nominal variables. To capture the effect of the different rules on real variables as well, one should consider a production economy in which consumption is endogenous and is also affected by the particular rule the monetary authority follows. In the next section, I describe a production economy version of the endowment economy just presented and analyze the effect of each rule on the volatility of economic variables.

MONETARY POLICY AND THE UNCOVERED INTEREST PARITY CONDITION: A PRODUCTION ECONOMY

Here I develop a production economy in which consumption growth is endogenous and depends on the particular monetary policy rule followed by the central bank. In contrast to the previous case of an endowment economy, now I cannot derive an analytical solution for the risk premium. However, the advantage of a production economy is that the monetary policy rule has a stronger effect on the risk premium, which generates larger differences between the two rules.

Theory

I follow the work of De Paoli and Søndergaard (2009) and Mihov and Santacreu (2013) to develop a small open economy model with two alternative rules: an IRR and an ERR. The small open economy, which is also the domestic economy, is modeled explicitly. The foreign economy is assumed to be exogenous (foreign output, inflation, and interest rates follow an AR(1) process).

In the small open economy, there is a representative consumer who chooses consumption, labor, and savings subject to a standard budget constraint. There is external habit in consumption, as explained in the previous section: Consumers care about their consumption relative to a subsistence level. Markets are complete, and consumers have access to a complete set of contingent securities that are traded internationally.

In this economy, consumption is an aggregate of both domestic and foreign goods (i.e., imports). There is home bias in consumption, which determines the degree of openness of

the economy. Consumers choose optimally how much to consume of each domestic and foreign good.

On the production side, each good is produced by a monopolistically competitive firm that uses labor according to a constant returns-to-scale production function. Production of goods is subject to an aggregate productivity shock, which is the only source of uncertainty in this economy. Firms take as given the demand by the final producer and set a price that is a constant markup over their marginal cost. In this model, prices are sticky à la Calvo. In each period, a constant fraction of firms set prices optimally, and the rest set the price from the previous period. This results in a forward-looking process for inflation: Inflation today depends on the output gap and expected future inflation. The model is closed with an international risk-sharing condition that (i) results from the assumption of complete markets and (ii) determines a relationship between the domestic and foreign interest rates and the expected rate of depreciation of the currency.

The central bank chooses a monetary policy instrument to react to fluctuations in inflation and the output gap, which in this model is defined as the difference between actual output and the output that would be obtained if prices were flexible. Consider, as before, two cases for the monetary policy rule: (i) a rule in which the monetary authority sets the interest rate and lets the exchange rate adjust with the international risk-sharing condition that arises from the assumption of complete markets (IRR), and (ii) a rule in which the monetary authority sets the exchange rate and lets the nominal interest rate adjust through the international risk-sharing condition (ERR). In this model, and to be more consistent with the rule actually followed by the monetary authority, I assume some degree of interest rate smoothing for an IRR and some degree of exchange rate smoothing for an ERR. That is, the rules are modeled as follows:

(i) IRR

$$i_t = \rho i_{t-1} + (1 - \rho) (\phi_y (y_t - y^*) + \phi_\pi (\pi_t - \pi^*)),$$

where $\rho \in (0, 1)$ is the degree of interest rate smoothing.

(ii) ERR

$$\Delta e_t^* = \bar{\Delta e} - \phi_y^e (y_t - y^*) - \phi_\pi^e (\pi_t - \pi^*)$$

where $\bar{\Delta e}$ is the depreciation required to reach the long-run equilibrium nominal exchange rate.⁸ I assume some smoothing in how the nominal exchange rate adjusts to its target level:

$$\Delta e_t = (1 - \rho_e) \Delta e_t^* + \rho_e \Delta e_{t-1}.$$

In contrast to the endowment economy in which I could obtain an analytical solution to capture fluctuations in the risk premium—and, hence, deviations from UIP—the production economy model has to be simulated. Mihov and Santacreu (2013) solve the model using a third-order approximation and compute second moments for the variables that the monetary authority cares about: domestic inflation, consumer price index (CPI) inflation, and output.

Table 4
Second Moments: Production Economy

Variables	IRR	ERR
Output	0.867	0.681
Consumption	0.054	0.044
Output gap	0.823	0.656
Domestic inflation	1.181	0.611
Depreciation rate	0.497	0.192
CPI inflation	0.912	0.391
Risk premium	1.09e-03	7.83e-05

Quantitative Results

Table 4 reports second moments of several economic variables and the risk premiums for the two alternative rules. The ERR generates lower volatility in the economy for both nominal and real variables. By smoothing the fluctuations in the nominal exchange rate, the central bank achieves lower volatility in both domestic inflation and CPI inflation, which also takes into account the inflation of prices for foreign intermediate goods. The main difference between this rule and one in which the exchange rate is fixed to the currency of another country (i.e., pegged) is as follows: Because a central bank that follows an ERR also reacts to fluctuations in real variables, such as the output gap, it can achieve less volatile nominal variables without increasing the volatility of real variables, as would happen with a peg. Output, consumption, and the output gap are less volatile with an ERR than with an IRR.

There are two reasons for the lower volatility: First, the actual implementation of the rule is important. In the model, the exchange rate today is predetermined, and the central bank announces the depreciation rate from time t to $t+1$. This implies, for example, that the model may not feature the standard overshooting result because the monetary authority determines the currency rate both today and at $t+1$. Second, deviations from UIP are important. One way to measure these deviations in the model is by computing the volatility of the implied risk premium, which as Table 4 shows, is lower for an ERR than for an IRR.

CONCLUSION

Analyzing the properties of alternative monetary policy rules is important from a welfare perspective. In this article, I study the impact of an ERR on the volatility of both nominal and real variables. Simulations of a production economy show that the ERR is more effective in achieving lower economic volatility than a standard IRR. There are two reasons for this: (i) The actual implementation of the policy matters, since the ERR avoids the overshooting in the nominal exchange rate, and (ii) the risk premium that generates deviations from UIP is less volatile with an ERR. Moreover, the ERR performs better than a peg, since the monetary

authority achieves exchange rate stability without relinquishing its ability to react to fluctuations of the economy.

I have incorporated several key issues in my analysis here. For instance, the credibility of the central bank is important for a policy such as the ERR to be successful and avoid large fluctuations in the nominal exchange rate. For a country with large capital inflows, lack of credibility in the monetary policy regime could trigger speculative attacks on the currency. Furthermore, the monetary authority's ability to adjust the exchange rate requires the authority to hold sufficient foreign reserves on its balance sheet. I have also abstracted from balance-sheet effects. Finally, the initial net foreign asset position of the country (whether it has a surplus or a deficit) matters for the performance of the rules that attempt to stabilize the nominal exchange rate. I leave these issues for future analysis on this topic. ■

NOTES

- ¹ The Federal Reserve's mandates are "maximum employment, stable prices, and moderate long-term interest rates... [with] inflation at the rate of 2 percent" (year-on-year inflation of personal consumption expenditures, or PCE; see Board of Governors of the Federal Reserve System, 2014). Moreover, the euro area mandate is "[t]o maintain price stability is the primary objective of the Eurosystem and of the single monetary policy for which it is responsible" (European Central Bank). And "The Bank of Japan, as the central bank of Japan, decides and implements monetary policy with the aim of maintaining price stability" (Bank of Japan).
- ² See Taylor (1993) for reference.
- ³ In its April 2015 monetary policy statement, the MAS announced: "MAS will therefore continue with the policy of a modest and gradual appreciation of the S\$NEER [Singapore dollar nominal effective exchange rate] policy band. However, the slope of the policy band will be reduced, with no change to its width and the level at which it is centered. This measured adjustment to the policy stance is consistent with the more benign inflation outlook in 2015 and appropriate for ensuring medium-term price stability in the economy" (Monetary Authority of Singapore, 2015).
- ⁴ The reaction function estimation is for Singapore with the sample period 1981:Q1–2012:Q4. Instrumental variable estimation with four lags of inflation and four lags of output gap is used to instrument for future inflation and the future output gap. See Mihov (2013) for more information.
- ⁵ Under log-normality, $\log(\mathbb{E}_t[M_{t,t+1}]) = \mathbb{E}_t[\log(M_{t,t+1})] + \frac{1}{2} \text{Var}_t[\log(M_{t,t+1})]$.
- ⁶ The details of this derivation are provided in Mihov and Santacreu (2013).
- ⁷ Along these simulation exercises, I set $\phi_\pi^{IRR} = \phi_\pi^{ERR} = 1.5$ and $\phi_c^{IRR} = \phi_c^{ERR} = 0.5$ to make the two rules consistent. However, Mihov and Santacreu (2013) find that the ERR still outperforms the IRR for different values of the coefficients of the rules.
- ⁸ I follow the convention that an increase in the exchange rate implies depreciation of the domestic currency.

REFERENCES

- Abel, Andrew B. "Asset Prices under Habit Formation and Catching Up with the Joneses." *American Economic Review Papers and Proceedings of the Hundred and Second Annual Meeting of the American Economic Association*, May 1990, 80(2), pp. 38-42.
- Alvarez, Fernando; Atkeson, Andrew and Kehoe, Patrick J. "If Exchange Rates Are Random Walks, Then Almost Everything We Say About Monetary Policy Is Wrong." *American Economic Review Papers and Proceedings*, May 2007, 97(2), pp. 339-45.
- Alvarez, Fernando; Atkeson, Andrew and Kehoe, Patrick J. "Time-Varying Risk, Interest Rates, and Exchange Rates in General Equilibrium." *Review of Economic Studies*, July 2009, 76(3), pp. 851-78.

Santacreu

- Backus, David K.; Gavazzoni, Federico; Telmer, Christopher and Zin, Stanley E. "Monetary Policy and the Uncovered Interest Rate Parity Puzzle." NBER Working Paper No. 16218, National Bureau of Economic Research, July 2010; <http://www.nber.org/papers/w16218.pdf>.
- Bank of Japan. "Outline of Monetary Policy." <http://www.boj.or.jp/en/mopo/outline/index.htm/>; accessed March 2, 2015.
- Benigno, Gianluca; Benigno, Pierpaolo and Nisticò, Salvatore. "Second-Order Approximation of Dynamic Models with Time-Varying Risk." *Journal of Economic Dynamics and Control*, July 2013, 37(7), pp. 1231-47.
- Benigno, Pierpaolo. "Price Stability with Imperfect Financial Integration." *Journal of Money, Credit, and Banking*, February 2009, 41(Suppl. s1), pp. 121-49.
- Board of Governors of the Federal Reserve System. "What Are the Federal Reserve's Objectives in Conducting Monetary Policy?" *Current FAQs*, September 19, 2014; http://www.federalreserve.gov/faqs/money_12848.htm.
- De Paoli, Bianca. "Monetary Policy Welfare in a Small Open Economy." *Journal of International Economics*, February 2009, 77(1), pp. 11-22.
- De Paoli, Bianca and Søndergaard, Jens. "Foreign Exchange Rate Risk in a Small Open Economy." Working Paper 365, Bank of England, March 2009; <http://www.bankofengland.co.uk/research/Documents/workingpapers/2009/wp365.pdf>.
- European Central Bank. "Objective of Monetary Policy" <https://www.ecb.europa.eu/mopo/intro/objective/html/index.en.html>; accessed March 2, 2015.
- Fama, Eugene F. "Forward and Spot Exchange Rates." *Journal of Monetary Economics*, November 1984, 14(3), pp. 319-38.
- Mihov, Ilian. "The Exchange Rate as an Instrument of Monetary Policy." *Monetary Authority of Singapore Macroeconomic Review*, April 2013, 12(1), pp. 74-82.
- Mihov, Ilian and Santacreu, Ana Maria. "Exchange Rates as an Instrument of Monetary Policy." Unpublished manuscript, June 2013.
- Monetary Authority of Singapore. "MAS Monetary Policy Statement." January 28, 2015; <http://www.mas.gov.sg/News-and-Publications/Speeches-and-Monetary-Policy-Statements/Monetary-Policy-Statements/2015/Monetary-Policy-Statement-28Jan15.aspx>.
- Monetary Authority of Singapore. "Monetary Policy." Undated; <http://www.sgs.gov.sg/The-SGS-Market/Monetary-Policy.aspx>; accessed March 9, 2015.
- Parrado, Eric. "Singapore's Unique Monetary Policy: How Does It Work?" IMF Working Paper 04/10, International Monetary Fund, January 2004; <http://www.imf.org/external/pubs/ft/wp/2004/wp0410.pdf>.
- Schmitt-Grohé, Stephanie and Uribe, Martin. "Pegs and Pain." NBER Working Paper No. 16847, National Bureau of Economic Research, March 2011; <http://www.nber.org/papers/w16847.pdf>.
- Svensson, Lars E.O. "Open-Economy Inflation Targeting." *Journal of International Economics*, February 2000, 50(1), pp. 155-83.
- Taylor, John B. "Discretion Versus Policy Rules in Practice." *Carnegie-Rochester Conference Series on Public Policy*, December 1993, 39, pp. 195-214.
- Verdelhan, Adrien. "A Habit-Based Explanation of the Exchange Rate Risk Premium." *Journal of Finance*, February 2010, 65(1), pp. 123-46.

A Model of U.S. Monetary Policy Before and After the Great Recession

David Andolfatto

The author studies a simple dynamic general equilibrium monetary model to interpret key macroeconomic developments in the U.S. economy both before and after the Great Recession. In normal times, when the Federal Reserve's policy rate is above the interest paid on reserves, countercyclical monetary policy works in a textbook manner. When a shock drives the policy rate to the zero lower bound, the economy enters a liquidity-trap scenario in which open market purchases of government securities have no real or nominal effects, apart from expanding the supply of excess reserves in the banking sector. In a liquidity trap, the Fed loses all control of inflation, which is now determined entirely by the fiscal authority. In normal times, raising the interest paid on reserves stimulates economic activity, but in a liquidity trap, raising the interest paid on reserves retards economic activity. (JEL E4, E5)

Federal Reserve Bank of St. Louis *Review*, Third Quarter 2015, 97(3), pp. 233-56.

The Great Recession of 2007-09 and its aftermath ushered in a new era for U.S. monetary policy. Prior to 2008, the Federal Reserve's policy rate stood in excess of 500 basis points. In 2008, the policy rate declined rapidly to 25 basis points, where it has remained ever since. Prior to 2008, the Fed's balance sheet stood at less than \$1 trillion dollars—about 7 percent of gross domestic product (GDP). Fed security holdings and liabilities are presently near \$4.5 trillion dollars—about 25 percent of GDP. Most of these liabilities exist as excess reserves in the banking system. Prior to 2008, excess reserves were essentially zero. The situation is so unusual that commentators frequently describe the Fed as sailing in uncharted waters.

The U.S. economy has recovered steadily, if somewhat slowly, since the end of the Great Recession. After peaking at over 10 percent in 2009, the civilian unemployment rate at the time this article was written was close to 5.5 percent. Despite the more than fourfold increase in the supply of base money, personal consumption expenditures (PCE) inflation undershot the Fed's 2 percent target throughout much of the recovery. With inflation varying between

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50 and 100 basis points below target and the labor market continuing to improve, the Fed has recently announced its willingness—some might say eagerness—to raise its policy rate as economic conditions dictate. Speculation over the date at which liftoff will occur is rampant in the financial pages of newspapers, as is concern over the wisdom of raising rates prematurely or leaving rates too low for too long.

People have many questions concerning the economic developments and issues just described. Why did interest rates plummet so dramatically in 2008? Why did the massive increase in base money appear to have no noticeable effect on the price level or inflation? Does the fact that most of this new money sits as excess reserves in the banking system portend an impending inflationary episode—an event that the Fed might have trouble controlling? Or will inflation continue to drift lower as interest rates remain low, replicating the experience of Japan over the past two decades? What, if anything, can or should the Fed do in present circumstances?

I answer these (and other) questions through the lens of a simple dynamic general equilibrium model that features three assets: money, bonds, and capital. In the model, money is dominated in rate of return but is nevertheless held to satisfy an exogenous demand for liquidity, modeled here as a legal reserve requirement. This reserve requirement binds when the nominal interest rate on bonds exceeds the interest paid on money. Excess reserves are held willingly when the nominal interest rates on bonds and money are the same. When this latter condition holds, the economy is in a liquidity trap. Open market purchases of bonds have no real or nominal effects, apart from increasing reserves in excess of the statutory minimum.

I demonstrate how the model can be used to interpret the effect of open market operations in normal times—defined as episodes in which money is dominated in rate of return and excess reserves are zero. An open market purchase of securities in this case has the effect of expanding the supply of liquidity in the economy, making it easier for banks and other entities to fulfill their reserve requirements. The policy rate (the interest rate on bonds) declines and the price level rises. As desired capital spending expands, banks increase their loan activity. There is no effect on long-run inflation when the inflation rate is anchored by fiscal policy.

I then consider a negative aggregate demand shock—technically, a news shock (Beaudry and Portier, 2014)—that leads agents to revise downward their forecasts over the future productivity of (or after-tax return on) contemporaneous capital spending. *Ceteris paribus*, the effect of such a shock is to induce a portfolio substitution away from capital and into government securities (money and bonds), placing downward pressure on bond yields and the price level. An open market purchase at this point places *additional* downward pressure on bond yields, stimulating investment and placing upward pressure on the price level. In this way, the monetary authority stabilizes both real economic activity and the price level.

When a negative aggregate demand shock is severe, the consequent decline in desired investment spending places significant downward pressure on bond yields as investors pursue a flight to safety, moving away from capital and into government securities. While the Fed can try its usual countercyclical measures at this point, the endeavor is ultimately stymied if its policy rate falls to the interest paid on reserves (usually zero, but presently 25 basis points). Additional open market operations at this stage have no effect on either real or nominal vari-

ables, apart from expanding the quantity of excess reserves. I argue that, to a first approximation, this is the reason the Fed's post-2008 quantitative easing (QE) programs appear to have had very little economic impact, apart from expanding the supply of excess reserves in the banking system.¹

While conventional open market operations are inoperative in a liquidity-trap situation, the Fed may still influence real economic activity through the interest it pays on excess reserves—the so-called IOER rate. The effect of altering the interest rate on reserves in a liquidity trap is very different from the effect it is likely to have in normal times. In normal times, banks wish to minimize their cash reserves because the yield on cash is low relative to competing investments. Lowering the interest rate on reserves increases the implicit tax on reserves, which reduces the demand for reserves, leading to a constraint on bank lending and investment. In a liquidity trap, banks willingly hold excess reserves and the same operation lowers the yield on *all* government debt, leading to a portfolio substitution away from government debt into private investment.

Finally, I demonstrate how a central bank theoretically loses all control over inflation in a liquidity trap. In this case, inflation is determined exclusively by the fiscal authority—in particular, by the growth rate of nominal debt (relative to the growth in its demand). If the fiscal authority supplies debt passively to meet market demand, the model implies a real indeterminacy: The economy can get stuck at any number of subnormal levels of economic activity, depending on which self-fulfilling inflation rate transpires. Determinacy is restored when the fiscal authority anchors the inflation rate by expanding the supply of debt on its own schedule and not in accordance with market demands.

THE MODEL ECONOMY

Preferences and Technology

In what follows, I describe a variant of Samuelson's (1958) overlapping-generations model, similar to the one developed in Andolfatto (2003). Time is discrete and the horizon is infinite, $t = 1, 2, \dots, \infty$. At each date $t \geq 1$, a unit mass of *young* agents enter the economy and a unit mass of *old* agents leave the economy. Apart from an initial unit mass of old agents (who live only for one period), each generation of young agents lives for two consecutive periods. The total population is therefore fixed across time and is at every date t divided evenly between the young and old. A young person at date t becomes an old person at date $t+1$.

Agents of every generation $t \geq 1$ are endowed with y units of output when young and zero units of output when old. Individuals are assumed to value consumption only in their old age. Consequently, the young face a trivial consumption-saving decision: It will always be optimal for them to save their entire income. The simplified consumption-saving choice permits me to focus on portfolio allocation decisions, the mechanism I wish to emphasize later. For simplicity, I also assume that preferences are linear.

Each young agent has access to an investment opportunity where k_t units of output invested at date t yield $xf(k_t)$ units of output at date $t+1$, where $x > 0$ is an exogenous productivity

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parameter that governs the expected return to investment. Assume that the production function f satisfies $f''(k) < 0 < f'(k)$; that is, higher levels of investment generate higher levels of future output, but with diminishing returns to scale. As well, assume that $f'(0) = \infty$ so that some investment will always be optimal. Finally, assume that capital depreciates fully after it is used in production.

Welfare

The competitive equilibrium of this economy is autarkic—that is, $k_t = y$ for all t . If $xf'(y) < 1$, the economy is dynamically inefficient (the competitive equilibrium real interest rate is less than the population growth rate). As such, there is a welfare-enhancing role for government debt. As is well known, the golden rule allocation can be implemented as a competitive monetary equilibrium with a perpetually fixed stock of government debt (although, as we shall see below, one needs to worry about the stability properties of such an equilibrium).

The policy of maintaining a fixed quantity of nominal debt continues to remain optimal here even if, say, x were to follow a stochastic process because of my assumption of linear (risk-neutral) preferences. Generalizing the model to nonlinear preferences would, in this case, imply a role for state-contingent interventions essentially for the purpose of completing a missing intergenerational insurance market. I am reluctant to generalize the analysis in this manner, however, because the main points I wish to stress can be demonstrated much more cleanly in a linear world.

Apart from the desirability of government debt when $xf'(y) < 1$, the analysis below offers no welfare rationale for the policies examined. For example, I assume the existence of two forms of government debt, money and bonds, even though the model provides no theoretical rationale for two distinct forms of debt. Moreover, I assume that the government issues money and debt even in the case $xf'(y) > 1$. I also follow conventional practice in assuming exogenous government policy rules.

Government Policy

There are two nominal assets, money M_t and bonds B_t , each issued by the government. Bonds yield a gross nominal one-period (from t to $t+1$) yield denoted by R_t^b . I assume that money can potentially earn interest at rate R_t^m (think of this as interest paid on reserves). For simplicity, I set government purchases to zero. The interest and principal owed on maturing government debt $R_{t-1}^m M_{t-1} + R_{t-1}^b B_{t-1}$ must be financed by a combination of new debt and a lump-sum tax T_t ; that is,

$$(1) \quad R_{t-1}^m M_{t-1} + R_{t-1}^b B_{t-1} = T_t + M_t + B_t.$$

Let D_t denote the nominal value of the government's total outstanding debt at date t ; that is, $D_t = M_t + B_t$. In what follows, I assume that the fiscal authority determines the path of D_t and T_t , and I assume that the monetary authority determines the path of interest rates R_t^m, R_t^b along with the composition of the total debt $\theta_t = M_t/D_t$. Condition (1) shows explicitly how monetary and fiscal policy are interlinked through the government budget constraint.

Fiscal policy operates as follows. First, I assume that the fiscal authority grows the nominal debt at a fixed rate μ , so that,

$$(2) \quad D_t = \mu D_{t-1},$$

with the initial debt $D_0 > 0$ endowed to the initial old. With interest rates and debt composition determined by monetary policy, I assume that the fiscal authority passively adjusts the lump-sum tax T_t to satisfy the government budget constraint (1).

Because it will prove convenient to express variables in real terms, let p_t denote the date- t price level and define $\tau_t = T_t/p_t$, $d_t = D_t/p_t$. Using (2) and $\theta_t = M_t/D_t$, rewrite the government budget constraint (1) as follows:

$$(3) \quad \tau_t = \left[\frac{R_{t-1}^m \theta_{t-1} + R_{t-1}^b (1 - \theta_{t-1})}{\mu} - 1 \right] d_t.$$

In what follows, I assume that the tax τ_t (or transfer, if negative) falls entirely on the old at date t .²

Since money and bonds share identical risk and liquidity characteristics in the setup considered here, to motivate a demand for money when it is dominated in rate of return (i.e., when $R_t^b > R_t^m$) I assume that individuals are subject to a legal minimum reserve requirement. I specify the exact nature of this reserve requirement when I later describe individual decisionmaking.

With fiscal (and regulatory) policy set in the manner described earlier, I turn attention to investigating the properties of alternative monetary policies. In all of the monetary policies considered below, I assume that interest on reserves is set exogenously to some level R^m . In most models, it is assumed that money exists in the form of zero interest cash, so that $R^m = 1$. In the upcoming analysis, $R^m \geq 1$ is permitted, which suggests interpreting the relevant money supply as electronic central bank reserves.³

I consider three different monetary policy regimes. First, I model an interest rate peg $R_t^b = R^b \geq R^m$, where θ is determined by market forces. Second, I model a money-to-debt ratio peg $\theta_t = \theta$, where R^b is determined by market forces. Third, I consider a more general interest rate rule along the lines of Taylor (1993).

Decisionmaking

A young person is endowed with y units of real income. Since consumption is not valued when young, all income is saved, with savings divided among the three available assets: money (m_t), bonds (b_t), and capital (k_t). Thus,

$$(4) \quad y = m_t + b_t + k_t,$$

where m_t, b_t denote *real* money and bond holdings, respectively. Given a portfolio choice, future (old age) consumption is denoted by

$$(5) \quad c_{t+1} = x f(k_t) + R_t^b (p_t/p_{t+1}) b_t + R^m (p_t/p_{t+1}) m_t - \tau_{t+1}.$$

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Following Smith (1991), I assume that individuals must hold a minimum amount of cash reserves against their capital holdings; in particular,

$$(6) \quad m_t \geq \sigma k_t,$$

where $0 < \sigma < 1$ is an exogenous policy parameter. Much of what follows depends on whether the reserve requirement constraint is binding.

The reserve requirement (6) may seem peculiar because it appears to require agents to hold reserves against assets rather than liabilities. But as pointed out by Smith (1991), it is possible to map this specification into something that looks more realistic by reinterpreting the model in an appropriate way. Suppose, for example, that after acquiring the portfolio $y = m_t + b_t + k_t$, the young find it convenient to deposit $p_t[m_t + k_t]$ dollars in a bank (consisting of a coalition of young agents). The bank issues liabilities of equivalent value—that is, $p_t[m_t + k_t]$ dollars that are redeemable for a future monetary value of $p_{t+1}[xf(k_t) + R^m p_t m_t]$ dollars. A more realistic reserve requirement specifies that a minimum fraction ξ of bank liabilities $p_t[m_t + k_t]$ needs to be held as cash—that is, $p_t m_t \geq \xi p_t[m_t + k_t]$. If we define $\sigma \equiv \xi/(1 - \xi)$, then this more realistic reserve requirement corresponds exactly to (6). The representation in (4)-(6) then simply consolidates the balance sheet of banks and their depositors.⁴

Let us now characterize optimal behavior. Substitute (4) into (5) and form the expression

$$W_t = xf(k_t) + R_t^b (p_t/p_{t+1})[y - m_t - k_t] + R^m (p_t/p_{t+1})m_t - \tau_{t+1} + \lambda_t [m_t - \sigma k_t],$$

where $\lambda_t \geq 0$ is the Lagrange multiplier associated with the reserve requirement. Maximizing W_t (expected future wealth/consumption) with respect to m_t and k_t yields the following restrictions:

$$(7) \quad \lambda_t = (R_t^b - R^m)(p_t/p_{t+1})$$

$$(8) \quad R_t^b (p_t/p_{t+1}) = xf'(k_t) - \sigma \lambda_t$$

Condition (7) makes clear that the reserve requirement will bind tightly ($\lambda_t > 0$) if and only if bonds strictly dominate money in rate of return ($R_t^b > R^m$). If money cannot earn interest ($R^m \geq 1$) and if money does not earn interest ($R^m = 1$), then one could say that the reserve requirement binds tightly only when the economy is away from the zero lower bound (ZLB).

Condition (8) implicitly defines the demand for investment. This condition shows that the expected rate of return on capital spending exceeds (equals) the return on bonds when the reserve requirement binds (is slack). That is, when the reserve requirement binds, agents would prefer to expand their capital spending, since the return from doing so is higher than investing in bonds. But doing so means accumulating additional low-return cash. Hence, the reserve requirement serves as a tax on capital spending, and condition (8) equates the after-tax returns on capital and bonds.

Combine conditions (7) and (8) to form

$$(9) \quad xf'(k_t) = [(1 + \sigma)R_t^b - \sigma R^m](p_t/p_{t+1}).$$

Condition (9) characterizes investment demand k_t . This condition holds regardless of whether the reserve requirement binds. The demand for government assets is left to be determined. If $R_t^b > R^m$, then the demand for real money balances is given by $m_t = \sigma k_t$. That is, the demand for reserves is proportional to the demand for investment. The demand for bonds can then be determined residually from condition (4) as $b_t = y - m_t - k_t$.

When the reserve requirement is slack, money and bonds are viewed as perfect substitutes in individual wealth portfolios. With k_t determined by condition (9), the demand for government assets is well defined and given by $d_t = y_t - k_t$. But the individual demand for money and bonds is indeterminate. That is, any combination of m_t, b_t satisfying $m_t \geq \sigma k_t$ and $m_t + b_t = d_t$ is consistent with individual optimization. The implication here is that the demand for money and bonds will, in this case, accommodate itself to the respective supply of money and bonds without the need for any price adjustment.

Proposition 1 *The investment demand function k_t characterized by condition (9) is increasing in (i) the expected return to capital investment (x); (ii) the expected rate of inflation (p_{t+1}/p_t); and (iii) the interest rate on reserves (R^m). Investment demand is decreasing in the nominal yield on bonds (R_t^b).*

The proof of this proposition follows immediately from condition (9). Intuitively, an increase in x increases the expected productivity of capital and so stimulates capital spending. An increase in the expected rate of inflation reduces the real interest rate on competing nominal assets, stimulating a portfolio substitution away from these assets and into capital. It is worth emphasizing the effect on investment demand from an increase in the interest rate. Proposition 1 asserts that the answer depends on exactly *which* interest rate one is referring to. An increase in the interest rate on *bonds* has the effect here of reducing investment demand—agents substitute out of capital and into higher-yielding government securities. An increase in the interest rate on *reserves*, however, has the effect of stimulating investment demand. An increase in the interest rate on reserves lowers the cost of holding reserves, so agents are motivated to expand their holdings of reserves, which then permits capital spending to increase.⁵

EQUILIBRIUM

In any equilibrium, we have $M_t = p_t m_t$, $B_t = p_t b_t$, and $D_t = p_t d_t$. Because $D_t = \mu D_{t-1}$, the expected rate of inflation must satisfy

$$(10) \quad \Pi_{t+1} \equiv \left(\frac{p_{t+1}}{p_t} \right) = \left(\frac{D_{t+1}}{D_t} \right) \left(\frac{d_t}{d_{t+1}} \right) = \mu \left(\frac{d_t}{d_{t+1}} \right).$$

Now, combine (10) and (9) together with $k_t = y - k_t$ to form

$$(11) \quad xf'(y - d_t) = \left[\frac{(1 + \sigma)R_t^b - \sigma R^m}{\mu} \right] \left(\frac{d_{t+1}}{d_t} \right).$$

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Recall that $\theta_t \equiv M_t/D_t = m_t/d_t$. If the reserve requirement binds ($R_t^b > R^m$), then $\theta_t = \sigma(y - d_t)/d_t$, which when expressed in terms of d_t , becomes

$$(12) \quad d_t = \left(\frac{\sigma}{\theta_t + \sigma} \right) y.$$

If the reserve requirement is slack ($R_t^b = R^m$), then condition (12) can be ignored (since the composition of debt θ_t is irrelevant in this case). From the government budget constraint (3), we have

$$(13) \quad \tau_t = \left[\frac{R^m \theta_{t-1} + R_{t-1}^b (1 - \theta_{t-1})}{\mu} - 1 \right] d_t.$$

Interest Rate Peg

The first type of monetary policy I want to study is an interest rate peg: $R_t^b = R^b > R^m$. An *equilibrium* in this case consists of bounded sequences for d_t , τ_t , and θ_t that satisfy (11)-(13) for all $t \geq 1$. A *stationary equilibrium* is an equilibrium that satisfies $(d_t, \tau_t, \theta_t) = (d, \tau, \theta)$ for all t .

Note that the equilibrium here has a recursive structure. That is, condition (11) determines $\{d_t\}_{t=1}^{\infty}$. With d_t so determined, condition (12) determines the sequence of open market operations $\{\theta_t\}_{t=1}^{\infty}$ that are necessary to support the fixed interest rate regime. With $\{d_t, \theta_t\}$ so determined, condition (13) then determines the lump-sum tax τ_t that is necessary to balance the government budget.

Define $A^{-1} \equiv [(1 + \sigma)R^b - \sigma R^m]/\mu > 0$ and rewrite (11) as

$$(14) \quad d_{t+1} = A x f'(y - d_t) d_t \equiv P(d_t).$$

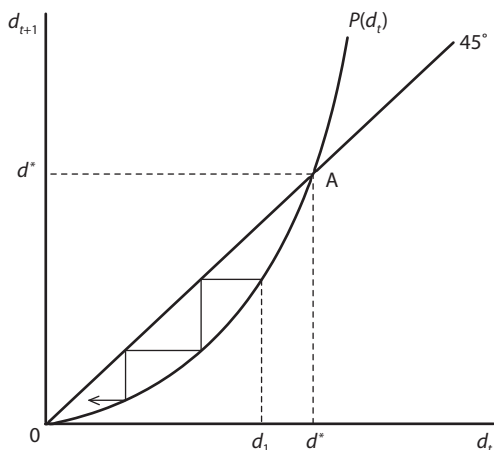
From (14), we see that conditional on a policy (R^b, R^m, μ) , two stationary equilibria are possible, one of which is degenerate ($d = 0$) and the other of which satisfies $1 = A x f'(y - d^*)$ with $0 < d^* < \infty$ (point A in Figure 1). Given the strict concavity of f , the nondegenerate stationary equilibrium is unique.⁶

Let me now investigate the stability properties of these two stationary states. First, note that $P'(d) = A x [f'(y - d) - f''(y - d)d] \geq 0$, with $P'(0) = 0$ and $P'(d) > 0$ for $d > 0$. Thus, $P(d)$ is increasing monotonically in d . Second, note that $\lim_{d \rightarrow 0} P(d)/d = P'(0) = 0$ and $\lim_{d \rightarrow y} P(d)/d = P'(y) = \infty$, so that $P(d)$ takes the general shape displayed in Figure 1, crossing the 45-degree line twice: once at the origin and once at point A.

The properties of $P(d)$ are familiar in overlapping-generations models of fiat money, where money is the only asset and whose nominal return is pegged (usually to zero). Under an interest rate peg then, there exists a continuum of nonstationary equilibria indexed by an arbitrary initial condition $d_1 \in (0, d)$ with the property that $d_t \rightarrow 0$.⁷ Equilibria of this form are hyperinflations, where the value of nominal government debt eventually approaches zero.⁸ Since $d_1 = D_1/p_1$, the multiplicity of nonstationary equilibria implies that the initial price level is indeterminate.

The nondegenerate steady-state $0 < k^* < y$ is characterized by

Figure 1
Equilibrium Dynamics (Interest Rate Peg)



$$(15) \quad xf'(k^*) = \left[\frac{(1 + \sigma)R^b - \sigma R^m}{\mu} \right].$$

Although k^* is unstable under the interest rate target rule, we can still make statements on how it depends on parameters.

Proposition 2 *If $R^b > R^m$, then k^* is increasing in x , μ , and R^m and is decreasing in R^b .*

To prove this, define $g(k) \equiv f'(k)(y - k)$ and note that $g'(k) = (y - k)f''(k) - f'(k)k < 0$. Intuitively, an increase in x increases the return on (and hence the demand for) capital. An increase in the inflation rate μ lowers the real return on government bonds, inducing a portfolio substitution away from bonds and into capital (and into money as well, to meet the reserve requirement). An increase in the interest rate on reserves, however, has the effect of stimulating capital spending here because it lowers the tax on holding money.

Under the policy regime described here, different policy rates R^b are associated with different money-to-debt ratios θ . In particular, from condition (12) $\theta = \sigma k / (y - k)$, so that θ is increasing in k . From Proposition 2 then, a higher R^b is associated with a lower θ (a tighter monetary policy). As well, since $p_t = D_t / (y - k)$, a higher R^b is associated with a lower price level, although note that the long-run inflation rate remains pinned by μ .

While the nondegenerate steady state is unstable under this policy regime, it turns out to be stable under the policy regime considered next.

Money-to-Debt Ratio Peg

The second type of monetary policy I want to study is a money-to-debt peg: $\theta_t = \theta > 0$. An equilibrium in this case consists of bounded sequences for d_t , τ_t , and R_t^b that satisfy (11)-(13)

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for all $t \geq 1$. A *stationary equilibrium* is an equilibrium that satisfies $(d_t, \tau_t, R_t^b) = (d, \tau, R^b)$ for all t .

When the reserve requirement binds ($R_t^b > R^m$), condition (12) determines the real quantity of government debt $d = (\sigma/(\theta + \sigma))y$ and the equilibrium level of capital spending $k = y - d = (\theta/(\theta + \sigma))y$. The implication of this is that the price level is now determinate, $p_t = D_t/d$ for all $t \geq 1$. Moreover, because $d_t = d$ for all $t \geq 1$, there are no nonstationary equilibria. The policy of pegging θ instead of R^b results in a unique equilibrium that is also a stationary equilibrium (as long as $R^b > R^m$).

Use (11) and (12) together with $\theta_t = \theta$ to derive this expression for the equilibrium bond yield,

$$(16) \quad R^b = (1 + \sigma)^{-1} \left[\mu x f' \left(\left(\frac{\theta}{\theta + \sigma} \right) y \right) + \sigma R^m \right] > R^m.$$

Proposition 3 *If $R^b > R^m$, then the equilibrium nominal bond yield R^b is strictly increasing in x and strictly decreasing in θ . The equilibrium level of capital spending k is increasing in x and θ .*

This proposition is easily validated by inspecting (16). The intuition is straightforward. An increase in x leads to an upward revision in the forecasted return to capital spending—that is, there is an increase in the demand for investment at any given interest rate. Agents are motivated to substitute out of bonds and into capital. But policy here pins down the real value of the outstanding supply of bonds. The decline in bond demand must therefore be fully absorbed as a decline in the price of bonds—that is, the bond yield—must rise.

An increase in θ corresponds to a (permanent) open market operation that expands the supply of cash relative to bonds. The added supply of reserves permits agents to expand capital spending. But as capital spending expands, the rate of return to capital declines (the marginal product of capital is diminishing). As capital investment becomes relatively unattractive at the margin, agents are induced to substitute into bonds, increasing their price (lowering their yield).

Proposition 3 together with (16) implies that there exists a number $\hat{x} > 0$ such that

$$(17) \quad R^b = \mu \hat{x} f' \left(\left(\frac{\theta}{\theta + \sigma} \right) y \right) = R^m.$$

When $R^b = R^m$, the reserve requirement is slack. Thus, for a given configuration of policy parameters (θ, μ, R^m) , a sufficiently bad shock ($x < \hat{x}$) will drive bond yields to their lower bound (the interest rate paid on reserves). For $x < \hat{x}$, the stationary value of real debt (d) is no longer determined by (12); it is instead determined by (11),

$$(18) \quad R^m = \mu x f'(y - d),$$

with associated price level $p_t = D_t/d$. Note that when the interest rate is driven to its lower bound, the policy regime effectively switches to the interest rate peg regime described earlier with all its associated indeterminacies. Condition (18) determines d (and k) independently of θ . In other words, open market operations that swap money for bonds do not matter, not even for the price level.⁹

Proposition 4 *If $R^b = R^m$, then an increase in θ (an expansionary open market operation) has no effect on the capital spending $k = y - d$ or the price level $p_t = D_t/(y - k)$. The only effect is to increase excess reserves $m - \sigma k > 0$, where $m = \theta d$. An increase in R^m increases the real demand for debt d and lowers the price level.*

DISCUSSION

The previous results demonstrate that the comparative statics of both policy regimes above are identical. The only difference is whether we want to think of monetary policy as targeting an interest rate, permitting the money-to-debt ratio to accommodate itself to the chosen rate, or whether we want to think of monetary policy as choosing the composition of government debt, permitting the yield on government bonds to clear the bond market. When money is dominated in rate of return, the model delivers standard textbook results in terms of the consequences of monetary policy (actions that affect the policy rate R^b). When shocks drive the economy to a region in the parameter space where the ZLB is in effect ($R^b = R^m$), the model delivers classic liquidity-trap effects (e.g., Krugman, 1998). Let me now use the model to interpret the U.S. macroeconomy and monetary policy before and after 2008.

Typical Recession and Policy Response

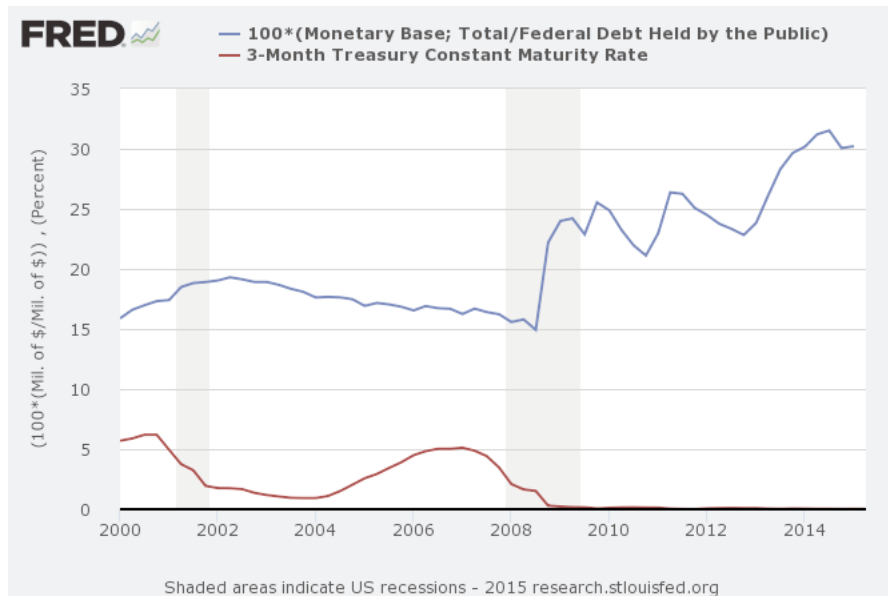
One way to generate a business cycle here is to assume that x is subject to change over time. My preferred interpretation of x is that it constitutes a news shock (Beaudry and Portier, 2014) realized at date t but that affects productivity at date $t + 1$. A decline in x_t at date t has the effect of reducing the demand for investment at date t without changing the supply of output at date t —that is, in this model, the real GDP is fixed at $Y_t = y + x_{t-1}f(k_{t-1})$. As such, a decline in x_t looks like a negative aggregate demand shock associated with an increasingly pessimistic outlook relating to the return to capital investment.¹⁰

Prior to 2008, the Fed's policy rate (R_t^b) was above the ZLB ($R^m = 1$). Consider the economic contractions in the early 1990s and early 2000s. As with all recessionary events, these episodes were associated with bearish outlooks, which I want to think of here as a sequence of progressively lower realizations of x . By Proposition 3, the effect of a lower x is to decrease investment demand, and hence decrease capital spending, which in turn leads to lower output. With long-run inflation anchored by the fiscal authority, such shocks can have only transitory effects on inflation, but they can have permanent effects on the price level. Absent an intervention, the effect of a lower x is to cause a decline in the price level, which reflects an increase in the real demand for government securities $d = y - k$. A sequence of bad news shocks would therefore generate a deflationary episode $p_t > p_{t+1} > p_{t+2}$, even as *expected* inflation remains anchored at μ .

Since $R^b > R^m$, there is scope for a monetary intervention that lowers R^b either directly or indirectly through open market operations that expand the size of the Fed's balance sheet (i.e., an increase in θ). By Proposition 3, the effect of such loosening of monetary policy is to stimulate capital spending, thereby preventing output from falling as much as it would absent the intervention. As well, another effect of the same intervention is to stabilize the price level.

Figure 2

Treasury Yield and Money-to-Debt Ratio



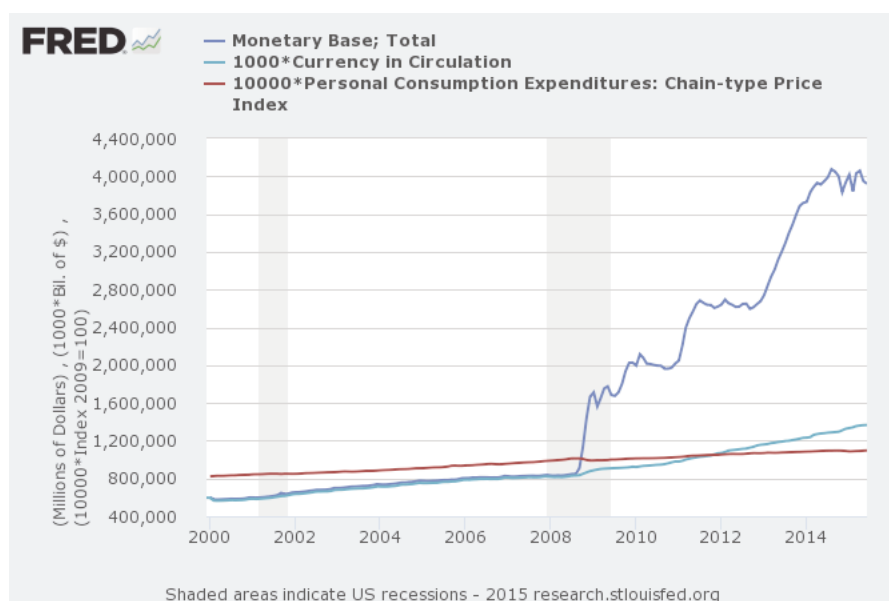
SOURCE: FRED®, Federal Reserve Economic Database, Federal Reserve Bank of St. Louis;
<https://research.stlouisfed.org/fred2/graph/?g=1xeZ>.

Incidentally, it is of some interest to ask what causes the interest rate to decline in a recession. To many observers, it appears that the Fed is causing the interest rate to decline, either directly through its policy rate or indirectly through its open market operations. As the previous analysis suggests, such a view is only partially correct. Consider, for example, the competitive equilibrium real interest rate in this economy absent any government $r = xf'(y)$. In this case, a decline in x will cause the interest to decline because (i) the supply of saving is fixed at y and (ii) a lower x implies a lower demand for capital. In other words, there are natural market forces at work pushing the interest rate lower in a recession that are independent of Fed actions. The question, really, is whether the Fed wants to accommodate these market forces. If it does not, the contraction in investment spending will be greater than it otherwise would be. In this sense, the Fed is not causing the interest rate to decline—it is simply accommodating market forces that “want” a lower interest rate.

The Great Recession and Quantitative Easing

The economic contraction of 2008 is unusual in at least two respects. First, it was unusually severe and, second, the market yield on U.S. Treasury securities fell to the interest rate on reserves. Consider Figure 2, which plots the 3-month Treasury yield and the ratio of base money to government debt held by the public. Note that the bond yield began to decline well

Figure 3
Monetary Base and the Price Level



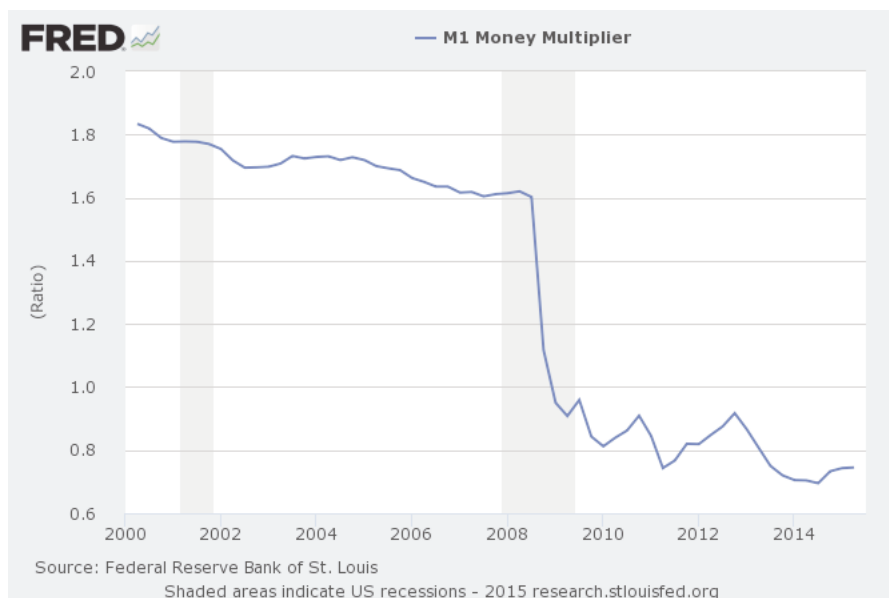
SOURCE: FRED®, Federal Reserve Economic Database, Federal Reserve Bank of St. Louis;
<https://research.stlouisfed.org/fred2/graph/?g=1xf0>.

before the start of the recession. This is consistent with deteriorating expectations (a decline in x) weakening investment demand and making bonds relatively more attractive. As the economic outlook continued to deteriorate throughout 2008, the economy contracted and yields continued to decline. With the failure of Lehman Brothers in the fall of 2008 and the economy on the verge of a financial crisis, the Federal Reserve announced the first of its large-scale asset purchase (LSAP) programs known as QE1. In the context of our model, one can interpret QE as a sharp increase in θ . With these events, the yield on short-term Treasuries declined essentially to their lower bound, $R^b \searrow R^m$ (see Figure 2, late 2008)—an effect consistent with the model prediction (see Proposition 2).¹¹

When $R^b = R^m$, Proposition 3 asserts that any further loosening of monetary policy (in the sense of increasing θ) is completely innocuous: Increasing the supply of base money does not even influence the price level, a prediction consistent with the evidence (Figure 3). When $R^b = R^m$, the economy is in a liquidity trap. That is, the economy is satiated with liquidity and any further attempts to inject liquidity (withdraw bonds) will only lead investors to hold reserves as if they were bonds. The evidence presented in Figure 3 is not inconsistent with this prediction: Most of the increase in the supply of base money since late 2008 is, in fact, being held as excess reserves in the banking system.

Another striking development in 2008 was the sharp decline in the money multiplier—the ratio of a broad money aggregate relative to the monetary base. See Figure 4, which plots

Figure 4
The Money Multiplier



SOURCE: FRED®, Federal Reserve Economic Database, Federal Reserve Bank of St. Louis;
<https://research.stlouisfed.org/fred2/graph/?g=1xf2>.

M1 (roughly currency in circulation plus demand deposit liabilities) relative to the monetary base. The model developed above is not rich enough to make a sharp distinction between currency in circulation M_t^c and bank reserves M_t^b , where $M_t = M_t^c + M_t^b$, so let me just assume that $M_t^c = \xi_t M_t$, where $0 < \xi_t < 1$ is exogenous. Suppose further that some exogenous fraction $0 < \alpha_t < 1$ of the economy’s capital stock is intermediated by banks, so that demand deposit liabilities in the model equal $p_t \alpha_t k_t$. In this case, M1 is given by

$$M1_t = \xi_t M_t + p_t \alpha_t k_t.$$

Market clearing requires $p_t = D_t/d_t$, which, when substituted into the expression above and after some manipulation, yields

$$(19) \quad \left[\frac{M1_t}{M_t} \right] = \xi_t + \alpha_t \left(\frac{k_t}{y - k_t} \right) \left(\frac{1}{\theta_t} \right).$$

Thus, holding fixed the parameters ξ_t , α_t , and θ_t , an exogenous bad news shock (a sudden decline in x) is predicted (by Proposition 2) to cause a sharp decline in the money multiplier. The intuition is simple: The contraction in investment demand leads to a proportional decline in bank financing. Incidentally, since $p_t = D_t/(y - k)$, the same shock induces a decline in the

price level (*ceteris paribus*), which did in fact occur and arguably would have been much more severe had D_t not expanded at nearly the same time. Once the economy is at the ZLB ($R_t^b = R^m$), the theory predicts that monetary policy in the form of changes in θ_t has no real or nominal effects except, as condition (19) reveals, on the money multiplier. The observed decline in the U.S. money multiplier since 2008 can then be explained as the consequence of the Fed's continued QE programs at the ZLB.

Of course, if monetizing a greater fraction of government debt is as innocuous as Proposition 3 suggests, then what are the rationales for the Fed's QE2 and QE3 programs? One answer is that the conditions stated in Proposition 3 are extreme: They describe a circumstance in which government bonds are literally perfect substitutes for interest-bearing cash reserves. In reality, the Fed's LSAP programs have included nontraditional securities—for example, higher-yielding longer-dated government bonds as well as agency debt.¹² Technically then, one might expect some effect, but one that is likely to be small given the historically low yields that presently characterize these nontraditional securities. If so, then this would explain the difficulty encountered by economists in identifying the quantitative effects of the Fed's LSAP programs (e.g., Thornton, 2014).

Why Is Inflation So Low?

Figure 5 plots the PCE inflation rate, the short-term nominal interest rate (the effective federal funds rate), and the real GDP growth rate since 2007. According to these data, economic growth has returned to pre-recession levels, the nominal interest rate is close to zero, and yet the inflation rate remains stubbornly below the Fed's 2 percent target. According to standard Phillips curve reasoning, accelerating growth should cause inflation to go up, not down. Is there a way to rationalize this observation?

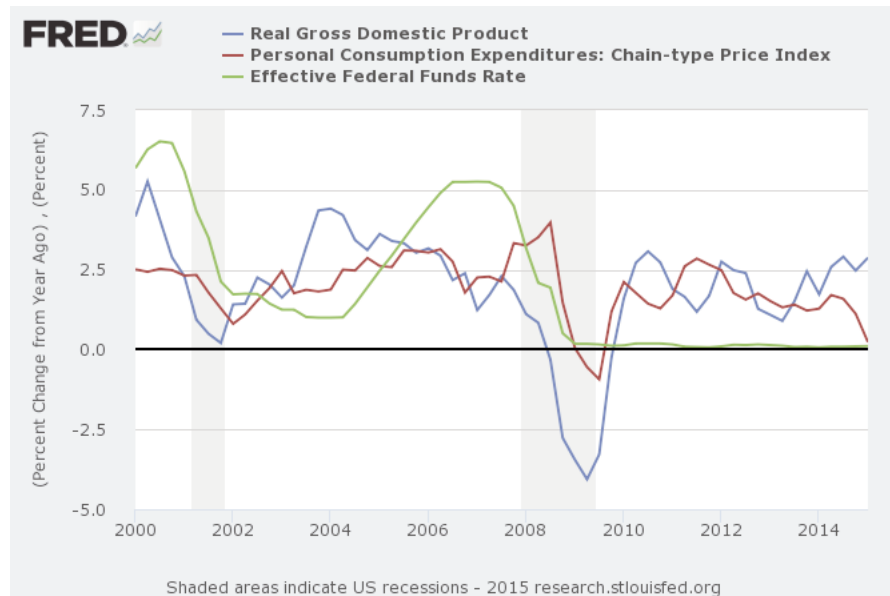
In the earlier specification of policy, I assumed that the fiscal authority mechanically chooses to grow its nominal debt at rate μ . While this policy alone does not pin down the price level, it does pin down the expected growth path of the price level—that is, it determines the expected rate of inflation. For the case in which $R^b = R^m$, monetary and fiscal policy together then determine the real rate of return on government debt R^m/μ , which, through the Fisher equation (15), then determines the equilibrium level of capital spending; that is,

$$(20) \quad xf'(k) = \frac{R^m}{\mu}.$$

An alternative specification of fiscal policy is that it permits its nominal debt to grow passively at the rate at which it is demanded. In conventional infinitely lived agent models, the real interest rate $r = xf'(k)$ is determined independently of monetary policy. In such a scenario, an improvement in the economic outlook (an increase in x) has the effect of increasing the real rate of interest. Since the nominal interest rate R^m is determined by policy, the Fisher equation (20) implies that the inflation rate must decline to satisfy the no-arbitrage condition equating the risk-adjusted real returns on capital and bonds. Thus, this is one possible explanation for why inflation declines as the economy improves. Andolfatto and Williamson (2015) describe

Figure 5

Output, Inflation, and the Interest Rate



SOURCE: FRED®, Federal Reserve Economic Database, Federal Reserve Bank of St. Louis;
<https://research.stlouisfed.org/fred2/graph/?g=1xf1>.

a similar mechanism triggered by financial sector healing that relaxes debt constraints following a crisis. In both cases, the critical assumption is that the fiscal authority grows its nominal debt to accommodate the market clearing inflation rate.

This alternative specification of fiscal policy in my overlapping-generations setting, however, introduces a real indeterminacy along the lines of Sargent and Wallace (1985). Technically, any (k, μ) pair satisfying $0 < k \leq \gamma$ is consistent with equilibrium. Since growth in the demand for nominal debt depends, in part, on how the price level is expected to grow, we have a situation in which private-sector inflation expectations can be self-fulfilling, with the fiscal authority expanding the supply of nominal debt to accommodate whatever inflation rate people choose to focus on. This indeterminacy implies that the economy may get stuck at a level of real GDP that is too high or too low relative to some criterion that policymakers judge desirable.¹³ The notion that the economy might get stuck in a suboptimal equilibrium is a key insight in Keynes (1936).¹⁴ Farmer (2013) is an important modern proponent of this view. Thus, even if the economy returns to its long-run real growth rate (in this model, zero), the economy may remain mired in a secular stagnation where economic activity is depressed relative to its potential.

A final observation in regard to the relationship between inflation and interest rates is that condition (20) is consistent with a perpetually negative real rate of interest and a strictly posi-

tive rate of inflation. This type of relationship is not consistent in conventional infinitely lived agent models. In this class of models, the real interest rate is strictly positive and invariant to policy. Consequently, a monetary policy based on a Friedman rule ($R^m = 1$) must imply deflation $\mu < 1$. Conventional models modified to permit transactional debt that (owing to a shortage of good collateral assets) incorporate a liquidity premium can, however, accommodate the evidence (again, see Andolfatto and Williamson, 2015, for an example).

Monetary Policy Going Forward

Monetary policy in the United States since the end of the Great Recession has been characterized by a policy rate driven essentially by the IOER $R^m = 1.0025$ and a balance sheet that is over four times larger than before the financial crisis, with most Fed liabilities existing as excess reserves in the banking system. As the real economy continues to improve, albeit at a slower pace than many have hoped for, and with inflation only 50 basis points below target, the Fed is preparing for *liftoff*—the date at which circumstances warrant increasing the policy rate. These circumstances evidently include continued improvement in the labor market and evidence that PCE inflation is unmistakably making its way back to its 2 percent target.¹⁵ Ultimately, the plan (or desire) is to normalize monetary policy, which the Fed describes as follows¹⁶:

Monetary policy normalization refers to the steps the Federal Open Market Committee (FOMC) will take to remove the substantial monetary accommodation that it has provided to the economy during and in the aftermath of the financial crisis that began in 2007. Specifically, monetary policy normalization refers to steps to raise the federal funds rate and other short-term interest rates to more normal levels and to reduce the size of the Federal Reserve's securities holdings and to return them mostly to Treasury securities, so as to promote the Federal Reserve's statutory mandate of maximum employment and price stability. The Committee plans to continue to use the federal funds rate as its key policy rate during the normalization process and to continue to set a target range for the funds rate when it begins to remove policy accommodation and for some time thereafter. When the Committee begins to normalize policy, it will raise the target range for the federal funds rate. This tightening of policy will be transmitted to other short-term interest rates and affect broader financial conditions in the economy.

How close is the U.S. economy to normal? By some metrics—for example, the 5.5 percent civilian unemployment rate—the U.S. economy seems not too far from normal. On the other hand, the expected real rate of return on short-maturity U.S. debt is *negative* 2 percent, substantially below its historical average of 2 percent.

As a practical matter, it is difficult to determine conclusively whether normality has been achieved. However, the model developed above can help shed some light on this question by providing a set of diagnostics. Think of the federal funds rate as R_t^b , which was over 5 percent prior to the crisis (see Figure 5). Also prior to the crisis, IOER was zero ($R^m = 1$) and excess reserves were zero as well. This state of affairs accords well with our theory, which predicts zero excess reserves when $R_t^b > R^m$. A combination of depressed economic conditions (lower x) together with a highly expansionary monetary policy (higher θ) then drove the traditional policy rate down to R^m , which was raised in 2008 from zero to 25 basis points.¹⁷ The diagnostic

is this: If the economy has indeed returned to normal (in the sense of x returning to its pre-crisis level), why hasn't the price level inflated in proportion to the expansion in the base money supply?

Two facts—the price level continuing to grow at a rate even less than the targeted inflation rate and the large quantities of excess reserves still held in the banking sector—suggest that economic conditions have not returned to normal, at least not along some important dimensions. Given a fixed R^m/μ , condition (20) suggests that the telltale sign of a normalizing economy (an increasingly optimistic outlook as parameterized by increases in x) should be robust growth in the level of capital spending (with a corresponding expansion in bank lending, to the extent that investment is bank financed) and positive price-level surprises (even as long-term inflation expectations remain anchored at μ). The Fed is presumably primed to lift off once it sees strong evidence of this type of price-level movement.

Monetary Policy with Excess Reserves

While the FOMC passage quoted earlier alludes to the idea of reducing the size of the Fed's security holdings, there seems to be little desire to embark on this path in the early stages of liftoff.¹⁸ Thus, for at least the foreseeable future, the Fed will conduct its policy in the context of a large balance sheet and excess bank reserves. Its policy tool in this scenario is essentially the interest it pays on reserves, R^m .¹⁹ Theoretically, the stationary equilibrium associated with an interest rate peg is unstable and induces price-level indeterminacy. However, hyperinflationary outcomes can theoretically be avoided by assuming that interest rate policy depends on macroeconomic conditions along the lines described by Taylor (1993). Consider, for example, a Taylor rule given by

$$(21) \quad \ln R_t^m = \max \left\{ \phi \ln \Pi_t + (1 - \phi) \ln \Pi^* + \ln r_t, \ln \hat{R} \right\},$$

where $r_t = xf'(k_t)$ is a measure of the real rate of interest, $\phi > 0$ is a parameter that governs how strongly the policy rate (here, interest on reserves) adjusts to deviations in inflation from target Π^* , and \hat{R} is the interest rate floor. The max operator restricts the policy rate from falling below the interest rate floor.²⁰

Consistent with the literature on Taylor rules, I assume that the fiscal authority passively accommodates inflation expectations, so that $\mu_{t+1} = \Pi_{t+1}^e$, where Π_{t+1}^e denotes the *expected* inflation rate. Along a perfect foresight path, $\Pi_{t+1}^e = \Pi_{t+1} = \mu_{t+1}$. As explained earlier, this specification of fiscal policy introduces a real indeterminacy, which can be resolved in a couple of ways. First, we could assume that $0 < k_t < \gamma$ is determined exogenously, in which case inflation expectations are determined by the Fisher equation (20); that is,

$$(22) \quad \ln \mu_{t+1} = \ln R_t^m - \ln [xf'(k_t)].$$

Second, we could assume that inflation expectations are formed exogenously, in which case condition (22) determines the equilibrium level of capital spending. In either case, I combine (22) with (21), invoking $\Pi_t = \mu_t$, and assuming $k_t = k$ to form

$$(23) \quad \ln \mu_{t+1} = \begin{cases} \phi \ln \mu_t + (1-\phi) \Pi^* & \text{if } \ln R_t^m > \ln \hat{R} \\ \ln \hat{R} - \ln [x f'(k)] & \text{if } \ln R_t^m = \ln \hat{R} \end{cases} .$$

The behavior for inflation described by (23) depends critically on whether the parameter ϕ is greater or less than unity. If $0 < \phi < 1$, then there is a unique steady-state inflation rate that corresponds to the target rate Π^* . Moreover, along the perfect foresight path, the inflation rate approaches the target rate monotonically from any initial condition $\mu_0 = p_0/p_{-1}$, with $p_0 = D_0/(y - k_0)$, where $0 < D_0 < \infty$ is determined exogenously by the fiscal authority.²¹ If $\phi > 1$, then there are two steady states, one of which is the one just described. The second steady state occurs when the nominal interest is at its ZLB, in which case the equilibrium inflation rate falls perpetually short of its target. As stressed by Benhabib, Schmitt-Grohé, and Uribe (2001), this latter low inflation equilibrium is stable and the intended equilibrium is unstable when the Taylor principle holds—this is, when $\phi > 1$.

Back in 2010, St. Louis Fed President James Bullard wondered out loud whether the Fed's low interest policy might lead to a disinflationary dynamic along the lines theorized by Benhabib, Schmitt-Grohé, and Uribe (2001).²² If this interpretation is correct, then the Fed's aggressive ($\phi > 1$) lowering of its policy rate may have resulted in the unintended steady state. From (23), we have

$$1 < \mu = \frac{\hat{R}}{x f'(k)} < 1.02 = \Pi^* ,$$

where $\hat{R} = 1.0025$ (the IOER rate at present).

If the fiscal authority has not anchored μ , then any combination of (μ, k) satisfying $\mu = \hat{R}/[x f'(k)]$ is consistent with equilibrium. In particular, a secular stagnation outcome is possible in which the level of economic activity (measured here by k) is less than normal—even if x has returned to normal. In this hypothetical world, an improvement in the economic environment brought about by, say, an increase in x has the effect of increasing the real interest rate (assuming that k either remains the same or does not expand so far as to keep the marginal product of capital at its initial level). The effect of this development is to put *downward* pressure on the inflation rate. According to the Taylor rule, the prescription for a decline in inflation is to reduce the nominal interest rate aggressively or, barring this possibility, to keep it at its lower bound for the indefinite future. Moreover, while a decline in x will have the effect of raising the inflation rate, the associated reduction in output is likely to warrant keeping (in the eyes of policymakers) the interest rate at zero in this case as well. In this manner, policymakers may find themselves stuck in a Japanese-style low inflation and low interest rate equilibrium.

Schmitt-Grohé and Uribe (2014) use a Taylor rule like (21) to generate a low inflation rate equilibrium along with a form of nominal wage rigidity that associates such an equilibrium with a suboptimal level of output. These authors propose a monetary policy to lift the economy out of its slump. In particular, they advocate *raising* the nominal interest rate R_t^m to its intended target $R^* = \Pi^* r^*$ for an extended period.²³ The authors claim that such a policy will boost infla-

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tion expectations, which, in their model, overcomes the assumed nominal wage rigidity and reestablishes the intended steady state as an equilibrium outcome.

Formally, the policy recommendation of Schmitt-Grohé and Uribe (2014) entails the Fed switching from $\phi > 1$ to $\phi < 1$ in the Taylor rule (21). Such a policy change would have the same inflation consequences in the model above. It is worth emphasizing that this result relies heavily on two critical assumptions. First, it depends critically on rational expectations. In particular, consider the Fisher equation (22): If the real interest rate $xf'(k)$ is fixed, then an increase in the policy rate *must* be associated with an increase in inflation expectations. Second, to accommodate these expectations, it is absolutely critical for the fiscal authority to stand willing to expand its nominal debt issue. One may reasonably question whether these assumptions hold even approximately in reality.

In any case, even if these two assumptions are met, the effect of changing monetary policy in the manner just described depends critically on what other assumptions one makes in terms of how the economy operates. For example, the same change in policy in the model I described earlier will have no effect on real economic activity. Along the transition path, the nominal interest rate rises one for one with expected inflation, leaving the real interest rate (and hence the marginal product of capital) unchanged. Admittedly, this is a very special case, but it illustrates the caution one should use when assessing the predictions of economic models.

An alternative specification of policy is to assume, as I did earlier, that μ is determined as an explicit target by the fiscal authority. In this case, the Fisher equation (22) implies

$$\ln[xf'(k_t)] = \ln R_t^m - \ln \mu.$$

If inflation (and inflation expectations) are anchored in this manner, then the effect of raising the policy rate R_t^m is to increase the real rate of interest, thereby depressing capital spending. Recall from Proposition 3 that the effect of raising the interest rate on reserves in this manner (and in a liquidity-trap situation) is to put downward pressure on the price level (without affecting the expected rate of inflation going forward). This is the sense in which a premature liftoff may be undesirable. A return to normality brought about by an increase in the economic outlook (x), on the other hand, has the effect of increasing capital spending and the price level. This is the circumstance in which liftoff may be desirable, which is why in practice the Fed is waiting for the signal of significant price-level pressure before it begins to raise its policy rate.

CONCLUSION

I began this article by posing a few questions. I now reflect on the answers to these questions suggested by the theory described here.

First, why did interest rates plummet so precipitously in 2008? The complete answer is not “the Fed did it.” There are natural market forces at work that drive interest rates lower when the economic outlook is depressed. Whether these diminished expectations were the by-product of a rational pessimism or an irrational fear is irrelevant with regard to the effect on market

interest rates. In such conditions, people want to save more and firms want to invest less. Both effects lower the real rate of interest. As for the Fed, one way to view its policy response is that it did everything it could to accommodate the market's desire for lower rates. Had the Fed not accommodated this desire, the effect would have been to keep real interest rates at an excessively high level, which would have exacerbated the contraction in spending brought about by the pessimistic outlook.

Second, I asked why the massive increase in base money appears to have no noticeable effect on the price level or inflation. The answer is that, with the Fed's policy rate driven down to its effective lower bound, increases in the supply of low-interest-bearing money for the purpose of purchasing low-interest-bearing debt are largely innocuous. The effect is just to relabel equivalent government liabilities from Treasury money to Fed money. The rise in *total* government debt during the crisis undoubtedly did have an impact on stabilizing the price level during the worst period of the financial crisis. But the QE programs initiated by the Fed did nothing to increase the total debt—they just had the effect of altering the composition of the debt and increasing the supply of excess reserves in the banking system. In this liquidity-trap scenario, it is not surprising that an increase in the base money supply has had little effect on inflation or the price level.

Third, does the fact that most of this new money sits as excess reserves in the banking system portend an impending inflationary episode—an event that the Fed might have trouble controlling? The short answer to this question is no. At least, not necessarily. The Fed has several tools at its disposal. If undue price-level pressure is detected, one option would be to engage in asset sales (that is, reverse the QE programs). Alternatively, the Fed could raise the IOER rate to enhance the real demand for reserve balances. In practice, tightening monetary policy in either of these manners is always controversial and subject to political scrutiny. But there is little question that the Fed has the tools at its disposal to keep inflation in check.

Fourth, I asked why inflation seems so low and whether inflation might continue to drift lower as interest rates remain low, replicating the experience of Japan over the past two decades. In the context of my model, long-run inflation is ultimately determined by the fiscal authority. In a liquidity-trap scenario, the central bank cannot affect inflation even in the short run. So the question is whether the enhanced demand for government debt will continue moving forward and whether the fiscal authority might show any willingness to increase primary government budget surpluses moving forward. I will not speculate on the prospect of future budget surpluses, but it seems safe to say that the demand for government debt is likely to abate as world economic conditions improve. When (or if) this happens, inflation is likely to creep back up to its target rate.

Finally, I asked what, if anything, the Fed should do in present circumstances. The Fed's congressional mandate is to use whatever tools it has at its disposal to keep inflation low and stable and to promote real economic activity. Since the end of the Great Recession, U.S. PCE inflation has remained low and stable, perhaps even too low by some tastes. The model suggests that the Fed's control over inflation (as opposed to the price level) is limited in a liquidity-trap scenario, but, of course, actual economic conditions do not correspond precisely to a pure liquidity trap. In any case, even in a liquidity trap the theory presented here shows how the

Fed's IOER rate can be used to blunt undue price-level pressure. The theory also suggests that keeping the policy rate low in present circumstances is consistent with promoting real economic activity and keeping inflation low and stable. ■

NOTES

- ¹ The three QE programs to date are QE1 (December 2008–March 2010), QE2 (November 2010–June 2011), and QE3 (September 2012–October 2014).
- ² The assumption that the lump-sum tax/transfer falls solely on the old is not innocuous. Among other things, it will imply that helicopter drops of nominal assets are neutral. This is because only the old possess nominal assets at the time of a monetary injection, so lump-sum transfers of money to them end up increasing everyone's money balances in proportion to their holdings.
- ³ I do not distinguish between cash and central bank reserves in this article, although it would be interesting to extend the analysis along this dimension.
- ⁴ I do not assume here that the young deposit their entire endowment with the bank because it would have the effect of rendering the demand for real money balances exogenous (when binding); that is, $m_t = \sigma y$. This defect is easily rectified, however, if I assume that the young value consumption so that deposits do not correspond to y . It would also be of some interest to experiment with other specifications—for example, requirements that some minimal amount of bonds also be held in reserve. The effect of an open market operation in this case would depend on which set of reserve constraints is binding.
- ⁵ Friedman (1960) advocated paying interest on (required) reserves to alleviate the implicit tax associated with a binding reserve requirement.
- ⁶ In a related model, Sargent and Wallace (1985) assert the existence of a continuum of stationary equilibria satisfying a restriction similar to (14); see their equation 6 (p. 283). The same indeterminacy exists here if A is left free, in which case policy is assumed to adjust passively to private-sector expectations and behavior.
- ⁷ Paths with the property $d_t \rightarrow \infty$ are ruled out as equilibria because they violate feasibility: $d_t \leq y$ for all t .
- ⁸ Thus, hyperinflation is possible even with a *contracting* supply of money ($\mu < 1$).
- ⁹ I remind readers that by an “open market operation,” I mean a swap of bonds for reserves for a given level of debt D_t . If the open market operation consists instead of financing a given ratio of additional debt $D_t + \Delta D_t$, then there would be a price-level effect, although in this model, a surprise injection of nominal debt is neutral.
- ¹⁰ Note that for positive analysis, it matters not whether expectations are rational. Pessimism here manifests itself in exactly the same way, regardless of its source. This distinction would, of course, matter for normative analysis.
- ¹¹ The reality is a little more complicated than what the model suggests. In particular, the QE1 intervention was largely in the form of lending against non-Treasury collateral. Moreover, the QE2 and QE3 interventions included purchases of agency debt. It is nevertheless true that the supply of base money relative to government debt rose, as Figure 2 shows.
- ¹² Agency debt consists mainly of new (not legacy) AAA-rated mortgage-backed securities issued by Fannie Mae and Freddy Mac.
- ¹³ One such measure is the Congressional Budget Office concept of potential GDP; see “A Summary of Alternative Methods for Estimating Potential GDP” (<http://www.cbo.gov/sites/default/files/03-16-gdp.pdf>).
- ¹⁴ Keynes (1936, Chap. 18) states “In particular, it is an outstanding characteristic of the economic system in which we live that, whilst it is subject to severe fluctuations in respect of output and employment, it is not violently unstable. Indeed it seems capable of remaining in a chronic condition of subnormal activity for a considerable period without any marked tendency either towards recovery or towards complete collapse.”
- ¹⁵ See the March 18, 2015, Federal Open Market Committee policy statement (<http://www.federalreserve.gov/newsevents/press/monetary/20150318a.htm>).

- ¹⁶ See “What Does the Federal Open Market Committee Mean by ‘Monetary Policy Normalization?’” (<http://www.federalreserve.gov/faqs/what-does-the-fomc-mean-by-monetary-policy-normalization.htm>).
- ¹⁷ In fact, the federal funds rate and the yield on very short-term Treasuries is presently *below* R^m , a phenomenon that is evidently a by-product of the fact that government-sponsored agencies such as Fannie Mae and Freddy Mac are not permitted to earn interest on their reserve accounts.
- ¹⁸ The lack of desire to sell securities seems to be driven by the fear that any such announcement might lead to a sell-off in the bond market, disrupting financial markets and hindering the recovery. See Neely (2014) for a description of the 2013 taper tantrum event.
- ¹⁹ At the date of liftoff, the Fed will in fact use an overnight reverse repo interest rate $R^b \leq R^0 \leq R^m$ to induce the federal funds rate higher. In the event that the federal funds rate does not respond as desired, the Fed is likely to increase the IOER rate in its attempt to maintain monetary policy control.
- ²⁰ Technically, I could allow negative nominal interest rates; see Kimball (2012). All that is important here is that a lower bound exists not too far below zero.
- ²¹ That is, I assume that the fiscal authority chooses the initial supply of nominal debt but thereafter supplies nominal debt perfectly elastically to accommodate market demand.
- ²² See Bullard (2010).
- ²³ Here, r^* corresponds to some natural rate of interest (e.g., $r^* = x^* f'(k^*)$, where x^* and k^* correspond to normal levels of productivity and capital spending, respectively).

REFERENCES

- Andolfatto, David. “Monetary Implications of the Hayashi-Prescott Hypothesis for Japan.” *Monetary and Economic Studies*, December 2003, 21(4), pp. 1-20.
- Andolfatto, David and Williamson, Stephen. “Scarcity of Safe Assets, Inflation, and the Policy Trap.” *Journal of Monetary Economics*, July 2015, 73, pp. 70-92.
- Beaudry, Paul and Portier, Franck. “News-Driven Business Cycles: Insights and Challenges.” *Journal of Economic Literature*, December 2014, 52(4), pp. 993-1074.
- Benhabib, Jess; Schmitt-Grohé, Stephanie and Uribe, Martin. “The Perils of Taylor Rules.” *Journal of Economic Theory*, January 2001, 96(1-2), pp. 40-69.
- Bullard, James. “Seven Faces of ‘The Peril!’” *Federal Reserve Bank of St. Louis Review*, September/October 2010, 92(5), pp. 339-52.
- Farmer, Roger. “Animal Spirits, Financial Crises and Persistent Unemployment.” *Economic Journal*, May 2013, 123(568), pp. 317-40.
- Friedman, Milton. *A Program for Monetary Stability*. New York: Fordham University Press, 1960.
- Keynes, John M. *The General Theory of Employment, Interest and Money*. London: Palgrave Macmillan, 1936.
- Kimball, Miles. “How Paper Currency Is Holding Back the U.S. Recovery.” *Quartz*, November 5, 2012; <http://qz.com/21797/the-case-for-electric-money-the-end-of-inflation-and-recessions-as-we-know-it/>.
- Krugman, Paul. “It’s Baaack: Japan’s Slump and the Return of the Liquidity Trap.” *Brookings Papers on Economic Activity*, 1998, 29(2), pp. 137-87.
- Neely, Christopher. “Lessons from the Taper Tantrum.” *Federal Reserve Bank of St. Louis Economic Synopses*, No. 2, January 27, 2014; http://research.stlouisfed.org/publications/es/14/ES_2_2014-01-28.pdf.
- Samuelson, Paul A. “An Exact Consumption-Loan Model of Interest with or without the Social Contrivance of Money.” *Journal of Political Economy*, December 1958, 66(6), pp. 467-82.
- Sargent, Thomas and Wallace, Neil. “Interest on Reserves.” *Journal of Monetary Economics*, May 1985, 15(3), pp. 279-90.

Andolfatto

Schmitt-Grohé, Stephanie and Uribe, Martín. "The Making of a Great Contraction with a Liquidity Trap and a Jobless Recovery." Unpublished manuscript, Columbia University, November 27, 2014; http://www.columbia.edu/~mu2166/Making_Contraction/paper.pdf.

Smith, Bruce D. "Interest on Reserves and Sunspot Equilibria: Friedman's Proposal Reconsidered." *Review of Economic Studies*, January 1991, 58(1), pp. 93-105.

Taylor, John B. "Discretion versus Policy Rules in Practice." *Carnegie-Rochester Conference Series on Public Policy*, 1993, 39(1), pp. 195-214.

Thornton, Daniel L. "QE: Is There a Portfolio Balance Effect?" *Federal Reserve Bank of St. Louis Review*, First Quarter 2014, 96(1), pp. 55-72; <http://research.stlouisfed.org/publications/review/2014/q1/thornton.pdf>.

Quantitative Macro Versus Sufficient Statistic Approach: A Laffer Curve Dilemma?

Alejandro Badel

This article highlights two approaches to tax policy for the top 1 percent of earners. On the one hand are dynamic general equilibrium models requiring complicated calibration and simulation algorithms and strong structural assumptions. On the other hand is the sufficient statistic approach, which attempts to parsimoniously reach the trinity of empirical, theoretical, and policy relevance. The author illustrates ongoing work highlighting explicit connections between these two approaches. (JEL D91, E21, H2, J24)

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The fact that the distribution of income exhibits substantial concentration is common to many eras and countries and has been well known for many decades.¹ More recently, the study of the earnings distribution over time and over the life cycle has gained attention in both the economics field and the media.

Regarding the life cycle, Deaton and Paxson (1994) used survey data from the United States, Taiwan, and Great Britain to document the fact that the dispersion of log earnings within a group of people born in the same year increases as they age. Following this tradition, Badel and Huggett (2014; BH hereafter) use data from the Social Security Administration (SSA), tabulated in Guvenen, Ozkan, and Song (2014), to document a similar pattern at the top of the earnings distribution: The ratio of the 99th percentile to the 50th percentile of earnings doubles over the working lifetime, and the mass of resources concentrated in the top 1 percent of the distribution increases substantially. Guvenen et al. (2015) also use SSA data and show that in the United States, individuals with higher lifetime earnings exhibit higher earnings growth over the life cycle. In particular, individuals in the top 1 percent of the lifetime earnings distribution experience an average earnings growth of approximately 1,500 percent over their working lifetime.

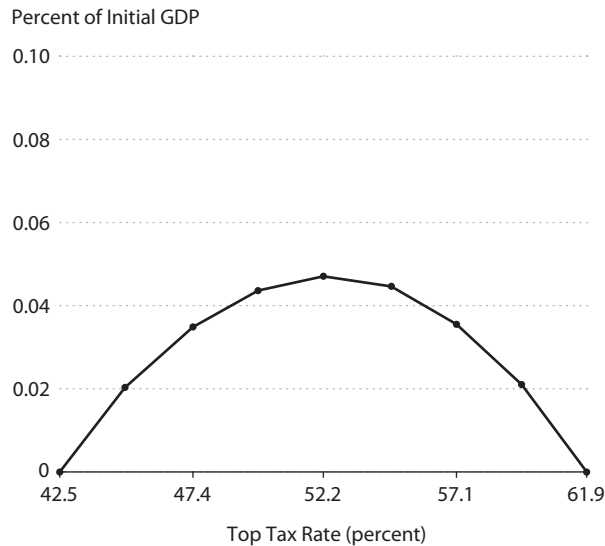
The analysis of income inequality over time has also attracted widespread attention. First, a literature based on survey data documents an increase in earnings dispersion in the United States. Heathcote, Perri, and Violante (2010) provide a compendium of survey-based measures

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Figure 1

Baseline Laffer Curve



NOTE: GDP, gross domestic product.

SOURCE: Model-generated Laffer curve from the baseline reform studied in Badel and Huggett (2014).

of economic inequality for the United States showing, among other things, that the variance of log annual male earnings increased steadily, almost doubling in magnitude, between 1967 and 2005. Piketty and Saez (2003) use tax administration data and find a U-shaped pattern of income concentration in the top 1 percent over the twentieth century. The recent resurgence of income concentration within the top 1 percent in the United States documented by Piketty and Saez (2003) has received widespread attention.

Casual observation of the basic fact that income and earnings are substantially concentrated suggests that government intervention might improve social welfare. In particular, taxing some earnings away from (relatively satiated) very high earners and giving it away to (relatively deprived) low earners can improve certain measures of social welfare. The catch is that higher taxes can create a disincentive for earnings generation and ultimately reduce the size of the “income pie.”

As tax rates are increased, the size of the “income pie” shrinks. Thus, the additional government revenue raised by increasing tax rates shrinks as well. In fact, tax rates may reach a point where additional increments actually reduce government revenue. These reductions can lead to a bell-shaped relationship between tax rates and government revenue known as the Laffer curve (for an example, see Figure 1).

The Laffer curve is related to the trade-off between distribution (how the pie is shared) and efficiency (the size of the pie) in two ways: First, if the tax rate to be chosen affects very

high earners (whose well-being is not very sensitive to small changes in after-tax earnings), then the revenue-maximizing tax rate approximately coincides with the socially optimal tax rate (i.e., in this case more revenue is better, regardless of the tax burden for top earners). Second, policymakers should avoid setting a tax rate higher than the top of the Laffer curve. Such a tax rate would likely be wasteful, as an equal amount of revenue can be generated at a lower tax rate. Trabandt and Uhlig (2011) consider tax systems consisting of a single flat rate and calculate the top of the Laffer curve within representative-agent growth models calibrated for the United States and several European countries.

Partly because of the connection of the Laffer curve with considerations about distribution versus efficiency, economists have attempted to calculate the top of the Laffer curve. A separate reason for calculating the top of the Laffer curve is the need to gauge the maximum amount of debt sustainable by a particular economy. Whether an economy is fiscally sustainable is a basic practical question faced by treasury departments and investors around the world. Clearly, the maximum amount of debt that can be eventually repaid depends directly on the maximum attainable amount of revenue.

A widely known article by Diamond and Saez (2011; DS hereafter) uses a technique known as the sufficient statistic approach to predict the top of the Laffer curve. The Laffer curve considered is the one that would result from increasing the U.S. top marginal income tax rate—that is, the marginal rate applying to the top 1 percent of earners. DS provide provocative advice stating that the U.S. top marginal income tax rate (including federal, state, local, and other taxes) should be raised from 42.5 percent to 73 percent. A similar approach has been used to predict the top of the Laffer curve for Britain (see Brewer, Saez, and Shephard, 2010, p. 110).

The article by DS follows the key guidelines of the sufficient statistic approach: The quantitative advice therein comes from deriving a simple formula and obtaining the numerical inputs into the formula from existing empirical studies. See Chetty (2009) for a review of the literature on the sufficient statistic approach. (Hereafter the simple formula is referred to as the DS formula.) This formula gives the revenue-maximizing tax rate as a function of only two parameters. One parameter is the Pareto coefficient at the 99th percentile of the income distribution, which captures the magnitude of resources generated by earners in the top 1 percent. The other parameter measures the propensity of top earners to reduce their income in response to higher tax rates. This second parameter is drawn from a large empirical literature on the “elasticity of taxable income” (ETI).²

A direct approach to calculating the top of the Laffer curve with respect to the top marginal tax rate is to use quantitative dynamic models with heterogeneous agents; here we will call this the quantitative macro approach. See Heathcote, Storesletten, and Violante (2009) for a review of this literature. In this tradition, Guner, Lopez-Daneri, and Ventura (2014) consider a reform that increases the marginal tax rate that applies to the top 5 percent of the income distribution, while Kindermann and Krueger (2014) and BH consider reforms that increase the marginal tax rate that applies to the top 1 percent of earners. In the first two articles, the evolution of an agent’s labor productivity over the life cycle is driven by an exogenous probabilistic process. In contrast, BH consider a model where an agent’s labor productivity is determined by the accumulation of human capital, so it can be affected by tax reforms.³

The key features of the quantitative macro approach highlighted here are (i) dynamics through which agents take into account the future consequences of current decisions, (ii) household heterogeneity in initial endowments and shocks, and (iii) a life cycle such that agents live for finite spans of time. In this framework, a combination of incomplete insurance against idiosyncratic shocks and ex ante agent heterogeneity can deliver consumption, hours of work, and earnings distributions by age that resemble several aspects of those in U.S. data. These models are well suited to study issues of inequality and tax progressivity.

How are the sufficient statistic approach and the quantitative macro approach related? Badel and Huggett (2015) provide an answer consisting of two points:

- (i) Under fairly general conditions, there exists a revenue maximization formula (analogous to the DS formula) that predicts the top of the Laffer curve in dynamic models as a function of three elasticity parameters and three coefficients. In contrast to the DS formula, the Badel-Huggett formula applies to models with several sources of government revenue besides earnings (e.g., taxes on capital or consumption) and to models featuring certain anticipatory responses (e.g., changes in human capital accumulation or savings that occur in anticipation of higher future tax rates). Badel and Huggett (2015) show how to map decisions in several dynamic and static models into the terms of the formula.
- (ii) The popular reduced-form econometric methods used to estimate the key propensity parameter (ETI) that enters the DS formula do not adequately capture the magnitude of the underlying elasticity when applied in some dynamic settings—for example, when human capital takes a long time to readjust in response to a tax reform.

The connection suggested in points (i) and (ii) is that the quantitative macro approach and the sufficient statistic approach are conceptually compatible, but that the existing empirical methods used by the sufficient statistic approach so far are not reliable for capturing the elasticity that holds in dynamic models.

In the remainder of this article, we illustrate points (i) and (ii) in more depth. Readers are referred to Badel and Huggett (2015) for the theorem deriving the Badel-Huggett revenue-maximization formula and several formal examples illustrating the application of the formula.

AN APPLICATION OF THE SUFFICIENT STATISTIC APPROACH

We start by posing the formula used to form the DS quantitative advice. Consider a static model in which a fixed marginal rate τ applies to earnings beyond a threshold, e_0 . Then the per person tax revenue from earnings above a given earnings level, say e_0 , is given by $[\bar{e} - e_0]\tau$, where $\bar{e} \equiv E[e|e > e_0]$ denotes mean earnings among agents with earnings above the threshold. The revenue-maximization problem is therefore $\max_{\tau} [\bar{e} - e_0]\tau$. The solution to this problem implies that, at a maximum, the top marginal tax rate satisfies the formula below:

$$\tau^* = \frac{1}{1+a\varepsilon},$$

where $a \equiv \bar{e}/(\bar{e} - e_0)$ is the Pareto coefficient of the earnings distribution at percentile e_0 , an inverse measure of the thickness of the right tail of the earnings distribution above e_0 , and ε is the elasticity of \bar{e} with respect to the net-of-tax rate, defined as $(1 - \tau)$. That is,

$$\varepsilon \equiv \frac{d\bar{e}}{d(1-\tau)} \frac{1-\tau}{\bar{e}}.$$

The DS quantitative advice says that the revenue-maximizing top tax rate for the United States is $\frac{1}{1+1.5 \times 0.25} = 73$ percent. This follows from plugging into the formula the value $a = 1.5$, which is the Pareto coefficient at the 99th percentile of the income distribution in the United States in 2007, and the value $\varepsilon = 0.25$, a midrange value from the literature estimating the ETI with respect to the net-of-tax rate.

The Sufficient Statistic Approach within a Dynamic Model

The revenue-maximization formula used by DS is not generally valid in dynamic models. Intuitively, there are two reasons behind this statement: (i) The DS formula does not account for the reaction of agents below the top 1 percent of the income distribution to the top tax rate reform. Agents who anticipate entering the top 1 percent in the future may take anticipatory behavioral responses. (ii) The DS formula does not account for the potential response of revenue from non-income sources, such as capital income, to the top tax rate reform. For example, agents may hold less financial wealth in reaction to a higher top marginal tax rate for earnings. This would decrease their capital income and, therefore, their capital income tax contribution. Trabandt and Uhlig (2011) emphasize, for example, the degree to which labor tax cuts can be self-financing through higher revenues from other sources. Finally, note that either reason (i) or (ii) can matter either directly or through general equilibrium effects such as factor price adjustments.

Badel and Huggett (2015) provide a revenue-maximization formula that applies to steady-state equilibria of dynamic models. They consider economies in which individual decisions specify n types of flows or stocks that are subject to taxation, denoted by $y_1(x, \tau), \dots, y_n(x, \tau)$. These decisions depend on an agent's vector of characteristics, x , and the top marginal tax rate τ . The net tax contribution of an individual with type x is $T(y_1(x, \tau), \dots, y_n(x, \tau); \tau)$. The distribution of characteristics x across the population is exogenous.

The formula in Badel and Huggett (2015) relies on differentiability assumptions together with the following assumption on the structure of the tax system (Assumption A2' from Badel and Huggett, 2015):

$T(\cdot; \tau)$ is separable in that $T(y_1, \dots, y_n; \tau) = T_1(y_1; \tau) + T_2(y_1, \dots, y_n)$ and moreover, there is $\underline{y} \geq 0$ such that

- (i) $T_1(y_1; \tau) - T_1(\underline{y}; \tau) = \tau[y_1 - \underline{y}]$
- (ii) $T_1(y_1; \tau) = T_1(y_1; \tau')$ for all $y_1 < \underline{y}$ and $\tau' \in (0, 1)$.

Assumption A2' in Badel and Huggett (2015) begins by stating that the tax system is separable in the component that specifies the value of taxes from the first component of the vector of

decisions, y_1 . Part (i) then states that beyond a cutoff level \underline{y} of y_1 , the tax system is characterized by a flat marginal rate τ on y_1 . Finally, part (ii) states that an agent's taxes from source y_1 are invariant to the top tax rate τ if y_1 is below the cutoff \underline{y} .

Theorem 1 in Badel and Huggett (2015) states that the revenue-maximizing top tax rate formula is

$$\tau = \frac{1 - a_2 \varepsilon_2 - a_3 \varepsilon_3}{1 + a_1 \varepsilon_1}.$$

Detailed definitions for each of the statistics in the formula are provided in Badel and Huggett (2015). This formula is valid in both dynamic and static models. Compared with the DS formula, it includes two additional terms in the numerator. These terms take the value zero when the formula is applied within a version of the Mirrlees model (see Badel and Huggett, 2015, Example 1). Therefore, equivalence with the DS formula holds in that case. The numerator terms capture two types of responses to changes in the top tax rate τ . The term $a_2 \varepsilon_2$ captures the y_1 response of agents with $y_1 < \underline{y}$. The term $a_3 \varepsilon_3$ captures the tax implications of the y_2, \dots, y_n decisions (i.e., all decisions except the y_1 decision) of agents inside and outside of the top 1 percent.

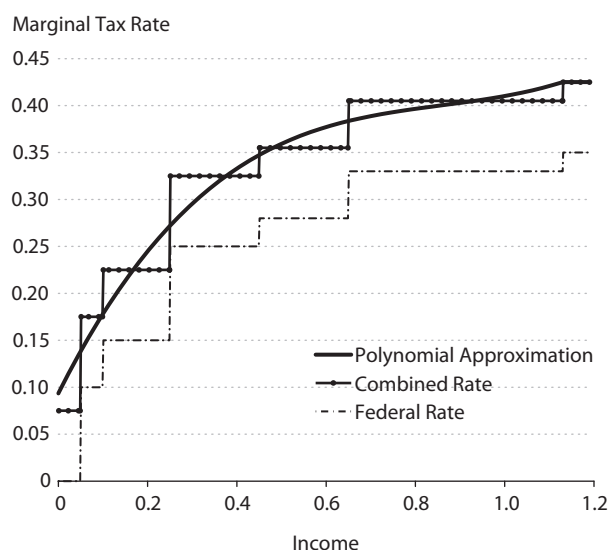
DYNAMIC MODELS WITH HETEROGENEOUS AGENTS

Badel and Huggett (2014) consider the top tax reform recommended by DS within a human capital model. In the human capital model, agents differ in their initial human capital and learning ability. Agents start their working life at age 23 and retire at age 62. During their working lifetime, agents choose their savings and how to allocate their time into three activities: learning, working, and leisure. Learning ability, learning time, existing human capital, and idiosyncratic shocks determine an agent's accumulation of human capital from one year to the next. During their working lifetime, agents pay individual and payroll taxes on their earnings and also pay taxes on the financial returns from saving. During retirement, agents consume out of their savings and their social security income. A steady-state equilibrium of the model features a constant interest rate determined at each point in time by the total savings and labor supply of all the generations alive.

The model is calibrated to match several features of the U.S. earnings distribution by age. The calibrated model can replicate the increase in earnings dispersion over the life cycle observed within the top 1 percent of earners and that observed between the 50th and the 99th percentile of the U.S. earnings distribution.⁴ Also, the model is calibrated so that an instrumental variables (IV) regression applied to data from the model matches the labor supply regression coefficient calculated by MaCurdy (1981).⁵ This coefficient is conventionally viewed as an important measure of the sensitivity of the labor supply to changes in wages. The model tax system captures key features of the U.S. tax system such as the progressive nature of the individual income tax schedule and the flat rate in the top bracket.

The Laffer curve that holds in the model is calculated. Each point of the Laffer curve corresponds to a steady-state equilibrium of the model with each equilibrium featuring a different

Figure 2A
Benchmark Individual Income Tax System



NOTE: Tax bracket cutoffs are expressed as multiples of the 99th percentile of income in 2010. The dashed line corresponds to the federal income tax schedule for married couples filing jointly in 2010. The dotted line adds 7.5 percent to all brackets to match the combined top marginal tax rate of 42.5 percent calculated by DS. The solid line corresponds to a polynomial approximation of the dotted line.

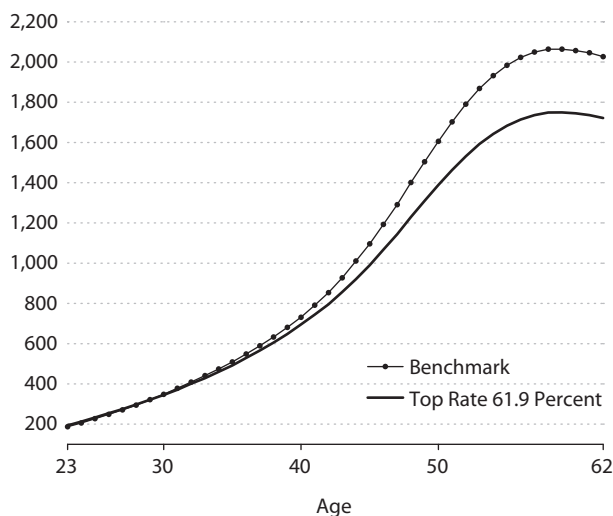
SOURCE: Badel and Huggett (2014).

top tax rate. The additional government revenue obtained under top tax rates higher than the baseline (42.5 percent, as calculated by DS) is rebated in equal lump-sum transfers. The Laffer curve plots the magnitude of these transfers as a share of baseline gross domestic product. Figure 1 displays the Laffer curve from the baseline tax reform and calibration in BH.

Two things stand out from the baseline Laffer curve in BH: (i) The revenue-maximizing tax rate is only 52.2 percent, substantially below the DS quantitative guidance of 73 percent, and (ii) the maximum revenue increase from the reform is 0.05 percent of initial gross domestic product.

To illustrate the tax reform, Figure 2A plots the marginal tax schedule. The note under Figure 2A explains how the model tax schedule is based on the U.S. tax code in 2010. To trace the Laffer curve in Figure 1, the top marginal tax rate is increased from 42.5 to 61.9 percent, leaving the tax rate unchanged below the top bracket.

Figure 2B shows how increasing the top marginal tax rate affects the average life cycle profiles of earnings for agents with high learning ability. Good learners have a strong incentive to invest time learning early in the life cycle and reap the benefits by working more later on. Growing work time and growing human capital due to learning imply that earnings grow strongly over the life cycle for high-ability agents. Such strong growth implies that many high-ability agents start their working life below the top 1 percent but reach the top 1 percent later

Figure 2B**Average Earnings by Age Among Agents with High Learning Ability**

NOTE: Average earnings (in model units) taken among agents in the top 1 percent of the learning ability distribution.
SOURCE: Badel and Huggett (2014).

in life. For these agents, a policy that increases the top tax rate lowers the return to human capital later in life but does not affect the opportunity cost of learning early in life. A fall in the return to learning time without a fall in its cost leads to less learning time and the clockwise flattening of earnings profiles shown in Figure 2B. An important consequence of the human capital mechanism is that the full effect of the top tax reform is complete only after several years because it depends on human capital accumulation choices made by agents over their working lifetime.

Applying the Sufficient Statistic Approach within a Dynamic Model

The sufficient statistic approach to taxing top earners consists of two parts. The first is a revenue-maximizing tax rate formula. The second is a set of estimated values for the parameters or statistics in the formula.

A key parameter in the DS formula is ϵ , the elasticity of top earnings with respect to the net-of-tax rate. DS consider a range of estimates and a preferred value of this parameter from the extensive literature that estimates an elasticity of taxable earnings with respect to the net-of-tax rate. This literature is reviewed by Saez, Slemrod, and Giertz (2012).

In this section, we summarize two different ways to apply the sufficient statistic approach within the human capital model. The experiments are as follows:

- (i) Use the Badel and Huggett (2015) formula to predict the top of the model Laffer curve under almost ideal conditions.⁶ The three coefficients (a_1, a_2, a_3) and the three elastic-

Table 1
Predicting the Top of the Laffer Curve

Parameter values	Implied revenue-maximizing top tax rate
$a_1 \times \varepsilon_1$	$1.97 \times 0.396 = 0.78$
$a_2 \times \varepsilon_2$	$3.07 \times 0.019 = 0.059$
$a_3 \times \varepsilon_3$	$0.043 \times 0.508 = 0.22$
$\tau^* = \frac{1 - a_2\varepsilon_2 - a_3\varepsilon_3}{1 + a_1\varepsilon_1}$	0.52
τ at peak of Laffer curve	0.52

SOURCE: Badel and Huggett (2015).

ities ($\varepsilon_1, \varepsilon_2, \varepsilon_3$) are directly calculated within the model. Table 1 displays the parameter values and the implied revenue-maximizing top tax rate. In summary, the formula accurately predicts the top of the Laffer curve, and the numerator components (not present in the DS formula) are nontrivial.

- (ii) Use both parts of the DS approach to predict the top of the Laffer curve using data (i) from the baseline steady state of the human capital model (to calculate the Pareto coefficient a) and (ii) from a simulated tax reform conducted within the human capital model (to calculate an estimate of the elasticity ε). We use artificial panel data from a simulated tax reform to estimate the elasticity of top earnings with respect to the net-of-tax rate using reduced-form econometric methods from Saez, Slemrod, and Giertz (2012). The model-generated dataset emulates the key features of the empirical dataset used by Saez, Slemrod, and Giertz (2012) to provide estimates of ε_1 . Their dataset exploits the top tax rate increase embedded in the 1993 Omnibus Budget Reconciliation Act. The instrumental variables methods from Saez, Slemrod, and Giertz (2012) are followed closely. The results and methods are summarized in Table 5 in BH. The key result is that for the variety of empirical specifications considered by Saez, Slemrod, and Giertz, the regression coefficient obtained underestimates the true ε_1 , which is $\varepsilon_1 = 0.396$. Quantitatively, this implies that the range of top tax rate recommendations produced by the DS approach within the human capital model is above the rate that actually maximizes revenue in the model.

CONCLUSION

In this article, we review ongoing work connecting the application of the sufficient statistic approach and the quantitative macro approach to finding the revenue-maximizing marginal tax rate for top earners. Two key points are highlighted: First, Badel and Huggett (2015) derive a revenue-maximizing top tax rate formula that is valid within steady states of dynamic models.

Moreover, in a human capital model the Badel-Huggett formula predicts the top of the Laffer curve well. Second, when the inputs of the formula are obtained using existing reduced-form empirical methods for the ETI applied to model-generated data, the top of the Laffer curve can be overestimated. A likely reason for this result is that the ETI methods do not capture the long-run effects of human capital accumulation. ■

NOTES

- ¹ To illustrate this, consider the narration in Mandelbrot and Hudson (2004, pp. 153-4): Italian economist Vilfredo Pareto “gathered reams of data on wealth and income through different centuries, through different countries: the tax records of Basel, Switzerland, from 1454 and from Augsburg, Germany, in 1471, 1498, and 1512; contemporary rental income from Paris; personal income from Britain, Prussia, Saxony, Ireland, Italy, Peru. What he found—or thought he found—was striking. When he plotted the data on graph paper, with income on one axis and number of people with that income on the other, he saw the same picture nearly everywhere in every era. Society was not a ‘social pyramid’ with the proportion of rich to poor sloping gently from one class to the next. Instead, it was more of a ‘social arrow’—very fat on the bottom where the mass of men live, and very thin at the top where sit the wealthy elite.”
- ² The parameter is known in the literature as the ETI with respect to the net-of-tax rate.
- ³ A look at these three articles reveals widely different conclusions about the shape of the Laffer curve. The reasons for these differences can be clearly traced back to model structure, calibration strategy, and details of the specific reforms considered in each article. This is a well-known advantage of the quantitative macro approach. However, we leave a comparative analysis of these studies for future work.
- ⁴ One of the novel features in BH is the introduction of a bivariate distribution based on the Pareto lognormal for the joint distribution of initial human capital and learning ability. The thicker tails of this distribution, compared with those of the bivariate lognormal used in Huggett, Ventura, and Yaron (2010), enable the model to match some aspects of the top tail of the U.S. earnings distribution by age.
- ⁵ MaCurdy (1981) used Panel Study of Income Dynamics data for males 25 to 55 years of age. The regression equation in MaCurdy (1981) is $\Delta \log(\text{hours}_i) = \alpha_0 + \alpha_1 \Delta \log(\text{wages}_i) + v_i$, where i denotes an individual and v_i is a random disturbance.
- ⁶ The conditions are “almost” ideal because, even though the inputs of the formula are measured directly within the model, they are measured at the benchmark equilibrium (away from the optimum), while the formula is derived using a local argument at the optimum.

REFERENCES

- Badel, Alejandro and Huggett, Mark. “Taxing Top Earners: A Human Capital Perspective.” Federal Reserve Bank of St. Louis Working Paper No. 2014-017, October 2014; <https://research.stlouisfed.org/wp/2014/2014-017.pdf>.
- Badel, Alejandro and Huggett, Mark. “The Sufficient Statistic Approach: Predicting the Top of the Laffer Curve.” Working paper, Georgetown University, March 9, 2015; <http://faculty.georgetown.edu/mh5/research/formula.pdf>.
- Brewer, Michael; Saez, Emmanuel and Shephard, Andrew. “Means-Testing and Tax Rates on Earnings,” in Stuart Adam, Stephen Bond, Robert Chotes, et al., eds., *Dimensions of Tax Design: The Mirrlees Review*. Chap. 2. Oxford, UK: Oxford University Press, 2010, pp. 90-201; <http://www.ifs.org.uk/uploads/mirrleesreview/dimensions/ch2.pdf>.
- Chetty, Raj. “Sufficient Statistics for Welfare Analysis: A Bridge Between Structural and Reduced-Form Methods.” *Annual Review of Economics*, 2009, 1, pp. 451-88.
- Deaton, Angus and Paxson, Christina. “Intertemporal Choice and Inequality.” *Journal of Political Economy*, June 1994, 102(3), pp. 437-67; http://www.princeton.edu/rpds/papers/Deaton_Paxson_Intertemporal_Choice_and_Inequality_JPE1994.pdf.

- Diamond, Peter and Saez, Emmanuel. "The Case for a Progressive Tax: From Basic Research to Policy Recommendations." *Journal of Economic Perspectives*, Fall 2011, 25(4), pp. 165-90; <http://pubs.aeaweb.org/doi/pdfplus/10.1257/jep.25.4.165>.
- Guner, Nezih; Lopez-Daneri, Martin and Ventura, Gustavo. "Heterogeneity and Government Revenues: Higher Taxes at the Top?" Working paper, Arizona State University, April 2014; <http://gustavoventura.com/uploads/2/9/2/5/2925697/glv-april08-2014.pdf>.
- Guvenen, Fatih; Karahan, Fatih; Ozkan, Serdar and Song, Jae. "What Do Data on Millions of U.S. Workers Reveal about Life-Cycle Earnings Risk?" Federal Reserve Bank of New York Staff Report No. 710, February 2015; http://www.newyorkfed.org/research/staff_reports/sr710.pdf.
- Guvenen, Fatih; Ozkan, Serdar and Song, Jae. "The Nature of Countercyclical Income Risk." *Journal of Political Economy*, June 2014, 122(3), pp. 621-60; <https://fguvenendotcom.files.wordpress.com/2014/04/guvenen-ozkan-song-jpe-2014.pdf>.
- Heathcote, Jonathan; Perri, Fabrizio and Violante, Gianluca. "Unequal We Stand: An Empirical Analysis of Economic Inequality in the United States, 1967-2006." *Review of Economic Dynamics*, Special Issue January 2010, 13(1), pp. 15-51.
- Heathcote, Jonathan; Storesletten, Kjetil and Violante, Giovanni L. "Quantitative Macroeconomics with Heterogeneous Households." *Annual Review of Economics*, 2009, 1, pp. 319-54.
- Huggett, Mark; Ventura, Gustavo and Yaron, Amir. "Sources of Lifetime Inequality." *American Economic Review*, December 2011, 101(7), pp. 2923-54; <http://pubs.aeaweb.org/doi/pdfplus/10.1257/aer.101.7.2923>.
- Kindermann, Fabian and Krueger, Dirk. "High Marginal Tax Rates on the Top 1%? Lessons from a Life Cycle Model with Idiosyncratic Income Shocks." PIER Working Paper 14-036, Penn Institute for Economic Research, October 10, 2014; <https://economics.sas.upenn.edu/sites/economics.sas.upenn.edu/files/14-036.pdf>.
- MaCurdy, Thomas E. "An Empirical Model of Labor Supply in a Life-Cycle Setting." *Journal of Political Economy*, December 1981, 89(6), pp. 1059-85.
- Mandelbrot, Benoit B. and Hudson, Richard L. *The (Mis)behavior of Markets: A Fractal View of Risk, Ruin, and Reward*. New York: Basic Books, 2004.
- Piketty, Thomas and Saez, Emmanuel. "Income Inequality in the United States, 1913-1998." *Quarterly Journal of Economics*, February 2003, 118(1), pp. 1-39; <http://eml.berkeley.edu/~saez/pikettyqje.pdf>.
- Saez, Emmanuel; Slemrod, Joel and Giertz, Seth H. "The Elasticity of Taxable Income with Respect to Marginal Tax Rates: A Critical Review." *Journal of Economic Literature*, March 2012, 50(1), pp. 3-50; <http://pubs.aeaweb.org/doi/pdfplus/10.1257/jel.50.1.3>.
- Trabandt, Mathias and Uhlig, Harald. "The Laffer Curve Revisited." *Journal of Monetary Economics*, May 2011, 58(4), pp. 305-27.

