Central Bank Models:
Lessons from the Past and Ideas for the Future[1]

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I appreciate the opportunity to speak at this workshop on ideas for research on central bank models. The very idea that such a brain-storming session can provide useful direction for research shows a great deal of vision by the Bank of Canada. The history of model development and the views of economists and practitioners can be of great help in finding the most fruitful lines of research.

Monetary models have been a favorite topic of mine for many years, especially in the years since the financial crisis. I gave the keynote speech at the Bank of Canada in the heat of the financial crisis in November 2008 at a conference honoring retiring Governor David Dodge.[3] Debate had already begun about whether the cause of the crisis was faulty models or faulty policy, and the debate continues today with obvious implications for future research.

In keeping to the purpose of today's workshop, I will try to suggest research ideas useful to monetary policy making going forward. I will draw on past research on policy models and on current research, especially the chapters by Jesper Linde, Frank Smets, and Raf Wouters (2016)

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[1] Keynote Presentation at the Workshop "Central Bank Models: The Next Generation," Bank of Canada, November 17, 2016.

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[3] See Taylor (2008) which was also the genesis of my 2009 book *Getting Off Track: How Government Actions and Interventions Caused, Worsened and Prolonged the Financial Crisis*

and by Volker Wieland, Elena Afanasyeva, Meguy Kuete, and Jinhyuk Yoo (2016) in the new *Handbook of Macroeconomics* (2016) edited by Harald Uhlig and me.

Lessons from the Past

A short historical review of how economic models have been developed and used at central banks in the past offers important lessons for the future. I will start with that history—which of course includes the global financial crisis and the slow recovery in many countries—and then consider ideas for future research.

80 Years Ago

The first macroeconomic model was built 80 years ago by Jan Tinbergen in 1936. The model was Keynesian with 32 stochastic equations based on the macroeconomic ideas of John Maynard Keynes. Important for the purposes of this workshop, the model was developed to answer an important monetary policy question: Whether a small open economy's currency should be devalued in order to stimulate the economy. Of course, the currency was the guilder, the country was the Netherlands, and the model was of the Dutch economy. In effect the issue was whether the Netherlands should leave the gold standard as other countries were doing. The assessment was based on simulations of the model in which policy *instrument*—the exchange rate—was devalued and the impacts on the *target* variables—employment and output—were examined. Tinbergen also made assumptions about the path of other currencies, thereby taking account of the possibility of currency wars.

The paper was prepared for a meeting of the Dutch Economics and Statistics Association and was presented on October 24, 1936. However, the paper was made available in September.

Then, on September 27, the guilder was devalued by about 20%, as the Netherlands abandoned the gold parity of the guilder. The timing is certainly consistent with the Tinbergen model having been an influence in that decision, but, as in virtually all policy work with models since then, we will never know for sure.[4]

Tinbergen's model simulations of instrument variables and target variables set economists and statisticians off on a long line of research on how to build, estimate, and simulate policy models. The common framework involved calculating the impact of different *paths* for policy instruments—whether monetary or fiscal—on target variables. In order to make these calculations, one needed to have a structural model rather than a reduced form. Hence, research began in the 1940s and 1950s at the Cowles Commission and Foundation at Chicago and Yale, and elsewhere, on how to estimate the structural parameters of simultaneous equations systems. Soon people went beyond full information maximum likelihood to develop limited information maximum likelihood and two-stage least squares. Debates between Keynesians and monetarists took place with such models, and Lawrence Klein took the research further by building more complex models in the 1950s.

Macro Models Come to Central Banks

After a considerable lag the research staffs of central banks began to adopt these models sometimes in collaboration with academics. In the 1960s the RDX1 model (and then RDX2 and RDXF) was developed at the Bank of Canada. A paper by Helliwell, Officer, Shapiro, and Stewart (1969) tells that story.

[4] Dhaene and Barten (1989) provide an excellent discussion of the Tinbergen model simulations and the devaluation decision.

Also in the 1960s the MPS (MIT-PENN-SSRC) model with 75 stochastic equations was adopted by the Federal Reserve. Papers by de Leeuw and Gramlich (1969) and by Ando and Rasche (1971) tell the Fed story. And it was the same story at many other central banks.

40 Years Ago: A Paradigm Shift from "Path Space" to "Rule Space"

But about half way through this 80-year history, there was a major paradigm shift. Views changed about how models should be used for monetary policy evaluation. I would describe it as a shift from policy evaluation in "path-space" as in the models developed in the 1930s, 40s and 50s, to policy evaluation in "rules-space." In "path-space" one estimates the impact of a one-time path for the policy instruments on the target variables, usually through a simulation in the case of econometric models. In "rule-space" one estimates the impact of a policy rule for the instruments on the dynamic stochastic properties of the target variables.

The shift had many antecedents and many causes. One antecedent and cause was the work by Milton Friedman advancing the advantages of policy rules. People realized that many of Friedman's arguments regarding predictability and accountability applied to active feedback rules as well as to the constant money growth rate rules which Friedman favored. Moreover, it was discovered that a natural way to evaluate policy in the new dynamic or stochastic models of the economy was by simulating policy rules. This is how engineers had been designing servo-mechanisms to stabilize dynamic stochastic systems. The very early work by A.W. Philips on proportional, derivative and integral control is an example, and one that got me interested in the subject of monetary rules. Another factor leading to analysis with rules was research on models with unknown parameters that had to be estimated at the same time they were being used for policy, as in the work by T.W. Anderson and me (1976) at Stanford

Moreover, around this time, economists began to replace adaptive expectations in the earlier models with rational expectations. The newer rational expectations models led to a serious critique of conventional "path-space" policy evaluation approaches by Lucas (1976) and to concerns about dynamic consistency of such paths by Kydland and Prescott (1977). This research accelerated the shift to policy analysis in "rule-space." Moreover, the incorporation of improved ways to model wage and price dynamics—leading to the so-called New Keynesian models—meant that many of the problems confronting monetary policy makers could be approached by monetary policy rules—rather than by one-time changes in the money supply, the interest rate, the exchange rate, or any other policy variable. I happened to be involved in this shift in my own research, and I can recall the sense of excitement very well.[5]

This policy analysis in "rule-space" provided an underpinning for a new monetary framework. Many policy-oriented empirical models with rational expectations and sticky prices were constructed in the 1980s. Many of the models were for individual countries, but some were international multi-country models with integrated international capital markets, no-arbitrage conditions in the term-structure, forward-looking expectations and price and wage rigidities

Rule-Space Macro Models Come to Central Banks

As with the case of models in "path space," there was a lag between this paradigm shift and the incorporation of the approach into central banks. Difficult computational tasks with the larger rational expectations models needed by central banks created a significant barrier, but algorithms and computers improved, and change eventually happened. Early evidence of the change was the shift in the orientation of the applied Brooking Model Comparison program in

[5] Taylor (1968, 1974, 1979), Anderson and Taylor (1976)

the late 1980s and early 1990s. In the book by Bryant, Hooper and Mann (1993), I noted the change saying that "Whereas previous model-comparison exercises conducted by the Brookings Institution have looked at the effects on the economy of one-time changes in the instruments of monetary and fiscal policy—that is policy multipliers—this exercise has emphasized comparisons of the response of the economy to monetary policy regimes that are simplified policy rules."

So in the early 1990s the RDXF model was replaced at the Bank of Canada by the Quarterly Projection Model QPM. In their exposition of the new model, Poloz, Rose and Tetlow (1994) emphasized the computational challenges of solving models with rational or "model consistent" expectations noting that they relied on an iterative method for "solving forward-looking models [that] was developed by R. Fair and J. Taylor (1983)." Coletti, Hunt, Rose, and Tetlow (1996) noted that the "two important features of that dynamic structure [of QPM] are forward-looking expectations and endogenous policy rules." This modeling framework continued through the 1990s and into the 2000s at the Bank of Canada as a new dynamic model with rational expectations and sticky prices, called ToTEM (for Terms-of-Trade Economic Model), replaced QPM. Computation speeds and solution algorithms have also improved greatly; see Maliar, Maliar, Taylor and Tsener (2015).

Also in the early 1990s, the MPS model at the Federal Reserve was replaced by the FRB/US model. As stated by Brayton and Tinsley (1996) "FRB/US is a new quarterly econometric model of the U.S. economy [in which] expectations of private sectors are explicit, and these expectations, especially market perceptions of policy, constitute a major transmission channel of monetary policy." A good history of Fed model development is found in Brayton, Levin, Tryon, and Williams (1997). This new approach continued with newer models: Much as

ToTEM was introduced at the Bank of Canada, the SIGMA and EDO models were introduced at the Federal Reserve.

Similarities Across a Range of Models

Volker Wieland's macro model data base (MMB) provides a broader perspective on this new paradigm because it includes models at other central banks and research organizations.[6] The MMB is expanding all the time as more central banks and other policy organizations arrange for their models to be included, and Volker Wieland, Michael Binder and I have recently started a new Macro Model Comparison Initiative to facilitate transparency, robustness, and replicability of policy models.

Table 1 is a list of models in the MMB collection as they existed before the financial crisis. Wieland, Afanasyeva, Kuete, and Yoom (2016) have classified these models into first, second, and third generation new Keynesian models which have both price-wage rigidities and rational expectations forward-looking behavior.

Some representative models are identified in bold-faced italics. According to the Wieland et al (2016) classification, the Taylor multi-country model (1993) is a first generation New Keynesian model, the Christiano, Eichenbaum Evans (CEE-ACEL) model and the Smets-Wouters (SW) model are second generation, and the De Grave (DG) model is a third generation model because of is explicit treatment of financial frictions. The Bank of Canada ToTEM model of Canada is also classified as 2nd generation because it does not have a financial accelerator or similar mechanism.

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[6] The Macro Model Data Base can be found at http://www.macromodelbase.com/ For information on its origins and purpose see Wieland, Cwik, Müller, Schmidt and Wolters (2012).

Table 1. Pre-Crisis Monetary Models in the MMB Data Base

Small Calibrated Models
Rotemberg, Woodford (1997)
Levin, Wieland, Williams (2003)
Clarida, Gali, Gertler (1999)
Clarida, Gali, Gertler 2-Country (2002)
McCallum, Nelson (1999)
Ireland (2004)
Bernanke, Gertler, Gilchrist (1999)
Gali, Monacelli (2005)

Estimated US Models
Fuhrer, Moore (1995)
Orphanides, Wieland (1998)
FRB-US model linearized as in Levin, Wieland, Williams (2003)
FRB-US model 08 linearized by Brayton and Laubach (2008)
FRB-US model 08 mixed expectations, linearized by Laubach (2008)
Smets, Wouters (2007)
CEE/ACEL Altig, Christiano, Eichenbaum, Linde (2004)
New Fed US Model by Edge, Kiley, Laforte (2007)
Rudebusch, Svensson (1999)
Orphanides (2003b)
IMF projection model by Carabenciov et al. (2008)
De Graeve (2008)
Christensen, Dib (2008)
Iacoviello (2005)

Estimated Euro Area Models
Coenen, Wieland (2005) (ta: Taylor-staggered contracts)
Coenen, Wieland (2005) (fm: Fuhrer-Moore staggered contracts)
ECB Area Wide model linearized as in Dieppe et al. (2005)
Smets, Wouters (2003)
Euro Area Model of Sveriges Riksbank (Adolfson et al. 2007)
Euro Area Model of the DG-ECFIN EU (Ratto et al. 2009)
ECB New-Area Wide Model of Coenen, McAdam, Straub (2008)

Estimated Small Open-Economy Models
RAMSES Model of Sveriges Riskbank, Adolfson et al.(2008b)
Model of the Chilean economy by Medina, Soto (2007)
CA_ToTEM10--ToTEM model of Canada based on Murchison and Rennison (2006)

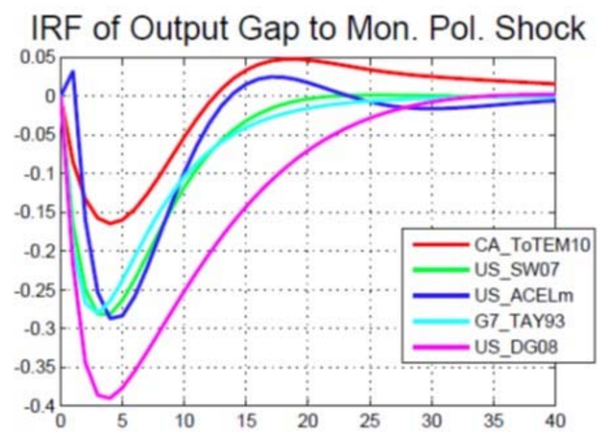
Estimated/Calibrated Multi-Country Models
Taylor (1993a) model of G7 economies
Coenen,Wieland (2002, 2003) G3 economies
IMF model of euro area by Laxton, Pesenti (2003)
FRB-SIGMA model by Erceg, Gust, Guerrieri (2008)

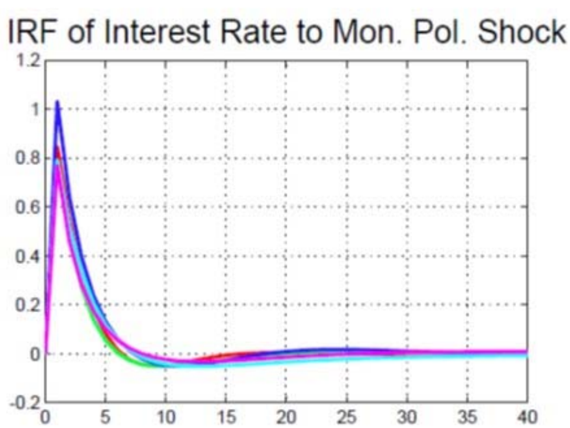
While these models are different in structure there is a surprising amount of consensus in what the models imply about the impact of monetary policy on the economy, as was shown for a number of models by Taylor and Wieland (2012). For example, consider the impact of a shock to a monetary policy rule of the form

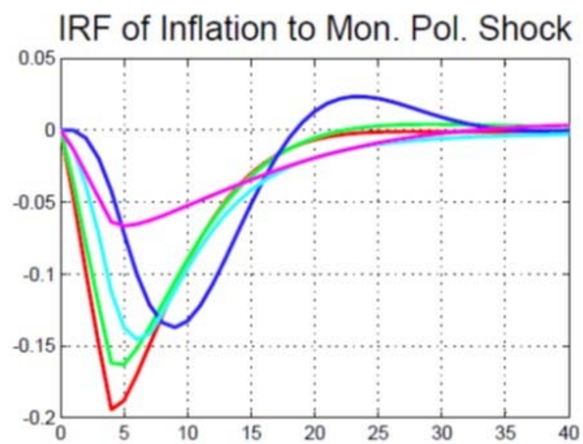
$$i_t = 0.81 i_{t-1} + 0.39\pi_t + 0.97 y_t - 0.90 y_{t-1} + \varepsilon_t^i$$

where *i* is the interest rate, *π* is the inflation rate, *y* is the output gap and *ε* is the shock. We call this the SW policy rule because it was used in the Smets-Wouters model. Figure 1 shows the impacts (impulse response functions, IRF) of a shock ε to the SW policy rule in the ToTEM, SW, CEE-ACEL, Taylor, and DG models on the interest rate, the inflation rate and output.

Figure 1: Model Comparisons of Monetary Policy Impact in Taylor, CEE-ACEL, SW, ToTEM, DG







Each of the models is designated with a different color code as shown on the right of Figure 1 using the model identification notation in the MMB. Note that there is a great deal of similarity between the models in all three generations, even though they have different structures, different degrees of micro-foundation, and were estimated over different time periods and. The interaction of the model and the policy rule in the first chart on the left is nearly identical. The lag patterns and dynamics of the effect on output and inflation are very similar. The impact on real output of the SW, CEE and Taylor models are nearly identical, while the impact is smaller for ToTEM and larger for DG. The ordering of the impact on inflation in ToTEM and DG are reversed. Of particular interest in light of the increased focus on financial frictions since the crisis is that the DG model does not show a marked difference from the other models that were available before the financial crisis.

Simple Rules for Policy from Complex Models

Recall that a main policy objective of these models was to find monetary policy rules which cushioned the economy from shocks and did not cause their own shocks. But the models were complex, so, at first, the policy rules were complex, and this raised serious doubts about the practical applicability of the whole "rule-space" framework. The question was whether simple practical rules consistent with the models could be found, and the answer turned out to be yes.

Rules like the Taylor rule in which the policy interest rate reacts to real GDP and inflation worked well in these models. Research with the models showed that the interest rate reaction to inflation should be greater than 1, the interest rate reaction to the GDP gap should be greater than 0, and the interest rate reaction to other variables should be small. For the Taylor rule the inflation target was 2% (taking into account measurement bias and the zero lower bound), and the equilibrium interest rate was 2% real and 4% nominal. The development of this simple rule was not a curve fitting exercise in which various instruments of policy were regressed on other variables. This simple rule was derived from first generation New Keynesian monetary models of type in Table 1.

The "rule-space" approach was also applied internationally. Research with the models demonstrated the near global optimality in rule-space of a Nash equilibrium in which each central bank followed an optimal policy for its country assuming other central banks would do the same. Thus the research showed that rules-based monetary policy would lead to good macroeconomic economic performance in the national economy and in the global economy.

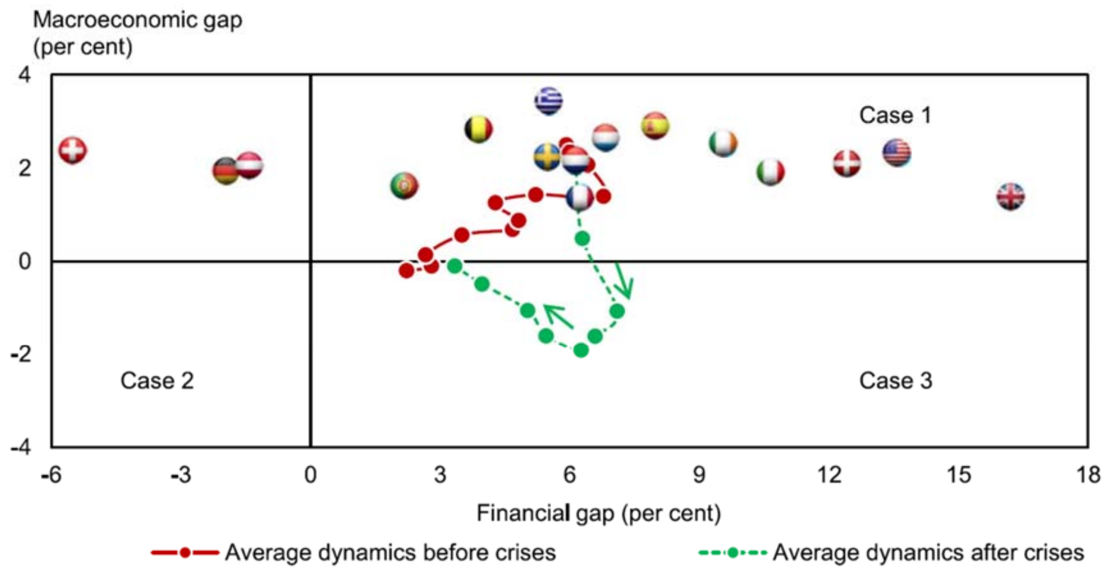
Some argued that there were problems with this approach. One was that it was too simple to assume that short term interest rate affects consumption and investment directly. But that is more a textbook, rather than a practical version, and many of the models in the MMB are more complex than that. Another argument is that the framework assumed away financial frictions. But Figure 1 shows that financial frictions were in some of those models, such as the financial accelerator in the De Graeve model, and the timing of the impact of policy was similar. There could have been more work with credit, but measurement problems forced many econometric modelers away from quantities toward prices. Some say that the framework did not deal with the zero lower bound. But it did. There was a 1% lower bound in early work. There was also the Reifschneider-Williams (2000) meta rule proposal to deal with the lower bound using "forward guidance" in "rule-space."

Moreover, this framework worked in practice: As central banks moved toward more transparent rules-based policies in 1980s and 1990s, including through a focus on price stability, economic performance improved. This connection between the rules-based policy and the performance was detected by Clarida, Gali, and Gertler (2000), and later confirmed by others. There was an especially dramatic improvement compared with 1970s when policy was highly discretionary and unfocused, and the models were used in a "path-space" mode. Mervyn King (2003) called it the NICE period for non-inflationary consistently expansionary, and there was also a near internationally cooperative equilibrium (another NICE) among most developed countries as there were few complaints about spillovers. So it was twice-NICE or NICE-squared. By the year 2000 many emerging market countries joined the rules based policy approach, usually through inflation targeting. Their improved performance contributed to global stability.

Monetary Policy Departs from Rule-Space

Unfortunately, it did not last. Some of the major central banks appeared to turn away from a "rule-space" guide to their decisions. The departure began a dozen years ago, before the financial crisis, when interest rates were set too low for too long. There is much evidence of monetary policy swinging away from rule-like policies, including that of Kahn (2010) and Ahrend (2010). Lane (2016) recently cites evidence in a revealing chart (reproduced in Figure 2) from an IMF Staff Report (2015) of average "macroeconomic gaps" and average "financial gaps" over a number of countries identified by their flags in the chart. Figure 2 shows that in the years before the financial crisis, interest rates should not have been so low in many countries. The use of unconventional policies in some countries has not been predictable or rule-like, and, in my view, has not worked very well, or at least has now reached diminishing or negative returns.

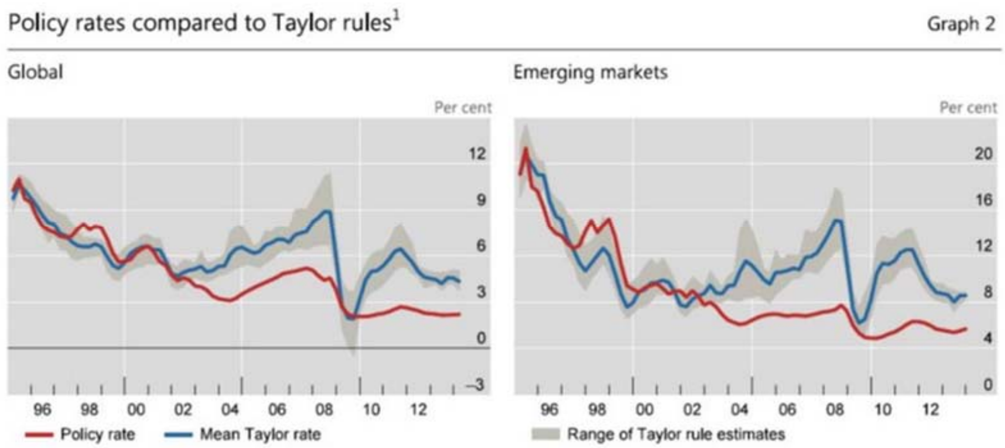
Figure 2. Macro gaps and financial gaps in several countries, before, during, after the financial crisis. Source: Lane (2016) and IMF Staff Report (2015)



Note: Data for selected advanced economies that faced a banking crisis in 2007–08. Vertical axis shows economic gap, measued as average of estimated output gap and inflation deviation from target. Horizontal axis shows financial gap, measured as average of deviations in the credit-to-GDP ratio and real house prices from historical trends.
Sources: International Monetary Fund staff estimates. Based on presentation by Giovanni Dell'Ariccia at Bank of Korea-IMF conference on *Leverage in Asia*, December 2015.

There is also evidence of a "Global Great Deviation," reported by Hofmann & Bogdanova (2012) and Shin (2016) of the Bank for International Settlements, shown in Figure 3. One reason for the global deviation is that central banks followed each other away from thinking about policy in rule-space. For example, there is evidence that the federal funds rate appears significantly in an estimated Canadian policy reaction function; see Gray (2013) and Siklos and Neuenkirch (2014). In many other countries, estimated central bank reaction functions have a significant reaction coefficient on foreign policy rates or on deviations from rules-based policy in other countries. See Carstens (2015), Edwards (2015).

Figure 3. Policy rates and Policy Rules around the World

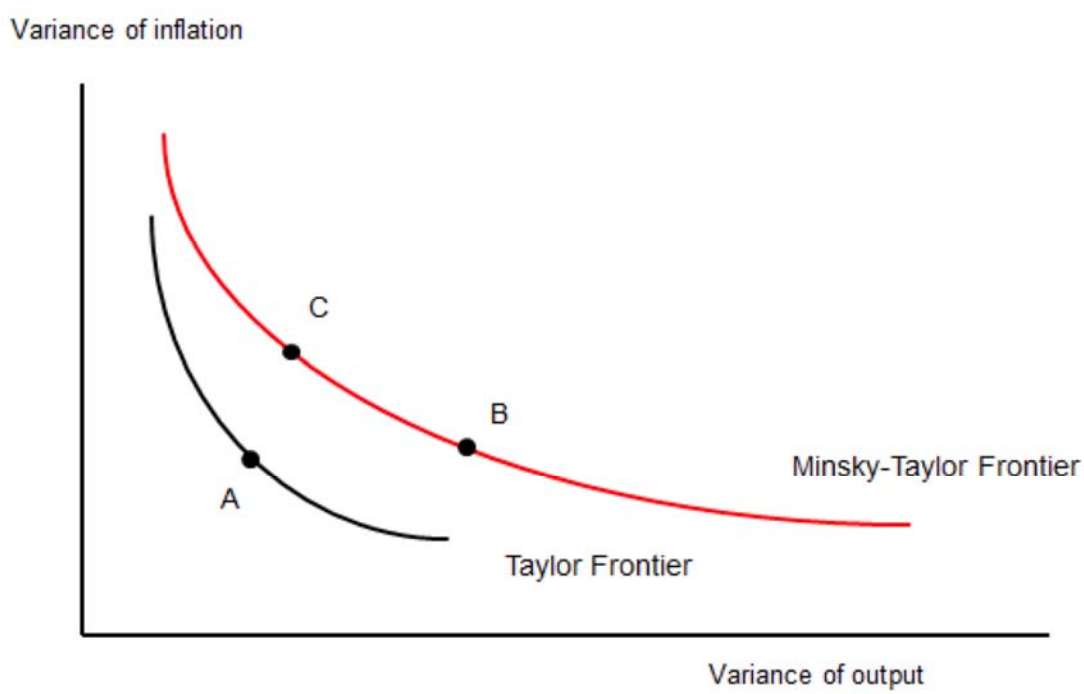


While there is an issue of causality versus correlation, econometric and historical evidence points to a close temporal connection between this deviation in policy and deteriorating performance. Following the Great Global Deviation, NICE ended in both senses of the word with the global financial crisis, the great recession & not-so-great recovery. Nikolsko-Rzhevskyy, Papell, Prodan (2014) provide econometric evidence for the United States and Teryoshin (2016) for other countries. Allan Meltzer (2012) provides historical evidence. There are also concerns about international spillover effects, and emerging market countries have been impacted with increased exchange rate and capital flow volatility

Thus, this evidence indicates that the problem was deviating from the rule-space framework. Of course there are other views. While Carney (2013) argues that "The adoption of inflation targeting in many countries generally coincided with a long period of macroeconomic tranquility [in which] a lower level of inflation volatility could now be achieved for any given level of output volatility," he goes on to argue that the poor performance of recent years occurred because "… the disruptive potential of financial instability—absent effective macroprudential policies—leads to a less favourable Taylor frontier, or what Mervyn King has called the Minsky-

Taylor frontier." Carney (2013) illustrated his argument with a tradeoff frontier as did King (2012). The Carney-King view is that performance deteriorated from point A to point B in the diagram because the frontier curve shifted. The view I offer here is that the move from A to B was due more to a move off the Taylor frontier due to a change in policy.

Figure 3 Tradeoff Curves from Carney (2013)



Ideas for the Future

This history suggests that a pressing problem for central bank research is to get back to a "rule-space" framework. The framework was good while it lasted, and still benefits countries that continue to implement it. The departure from this approach should be fundamentally reconsidered, which means finding out how to get back to the framework, understanding why the departure occurred, and figuring out how to prevent future departures.

But what can researchers do? What kind of research can help? Here are some ideas.

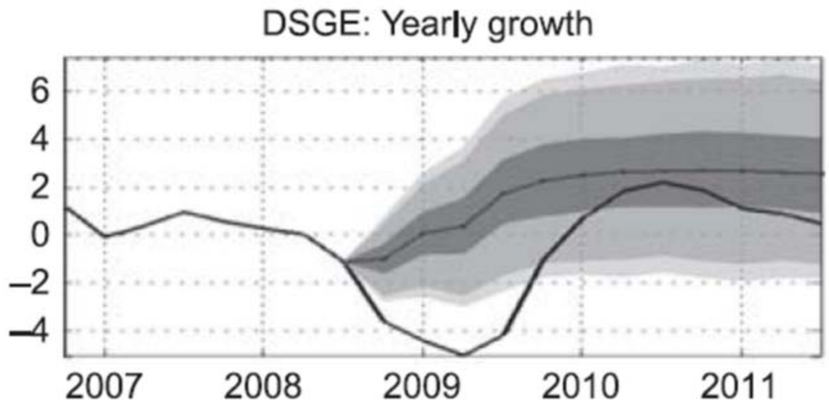
1. *Determine How Changes in Models Affect Policy Rules*

There are many ways that changes in the economy and models of the economy affect monetary policy. Examples include changes in the technology of financial intermediation, increased integration of the financial and real sides of the economy, behavioral economics factors (Gabaix (2016)), new distribution channels of monetary policy (Auclert (2016)), agent-based models (Ashraf, Gershman, Howitt (2016)), heterogeneous price and wage setting (Taylor (2016a)), and the impact of the zero (or effective) lower bound on the interest rate.

But the central question for central banks is the implication of these changes for monetary policy. The over-riding research goal should therefore be to understand how such changes affect monetary policy rules.

Consider, for example, how new or changing economic relationships related to the global financial crisis requires changes within a "rule-space" framework. According to Linde, Smets, Wouters (2016), there was something missing from the models used for monetary policy that was revealed in the financial crisis. As they put it "The 95% uncertainty band suggests that the large drop in output was completely unexpected from the point of the view of the DSGE model…" Figure 3, drawn from their paper, shows that the Great Recession was, in their words, "a highly unlikely tail event."

Figure 4: GDP Growth: Actual and Simulated in the Smets-Wouters model



They examine whether monetary policy shocks, risk premium shocks, or investment shocks were the reasons for the decline in output during the recession. Regarding monetary shocks, they note that "Loose monetary policy" was "a possible driver for the crisis" and that that their "estimated model lends some, but limited, support to this view," and in the end they find that "the magnitude of the deviations is not very large…" After considering other shocks, they conclude that the model needs a highly unlikely combination of adverse shocks."

They also look at the impact of adding economic relations. They find that the financial accelerator makes only a little difference: when you add a financial accelerator to their model, it does not help much in explaining the financial crisis. It changes the financial crisis from something like a 6-sigma event to a 3-sigma event—an improvement, but not ready to help much in the next crisis.

This raises the question as to whether a different financial accelerator might work. In recent work Christiano, Motto, and Rostagno (CMR) (2014) introduce a financial accelerator in which the GDP effect is much more persistent, though no larger upon impact. Volker et al (2016) find that reason for the greater persistence is a new "risk shock" which increases the external finance premium and creates amplification effects which are propagated.

Wieland et al (2016) then examine how the DG and the CMR financial accelerator models affect policy rules. They also consider two other models with financial constraints: Iacoviello and Neri (IN) (2010) and Iacoviello (IAC) (2005) which incorporate borrowing constraints in housing markets. They examine whether modifying a traditional policy rule to include credit growth would improve performance in these models. Table 2, which is drawn from Wieland et al (2016), shows the results of the study. They find that a policy rule which reacts to credit growth works better in some models, but worse in others. At the least the results show the potential for improving on policy rules by taking financial quantities into account.

Table 2: Stabilization of with Policy Rules that React to Credit Growth
Source: Wieland, Afanasyeva, Kuete, and Yoom (2016)

	US_DG08	US_CMR14	US_IAC05	US_IN10
Model-specific rule				
Baseline	5.8	47.6	12.3	6.9
Leaning (0.1)	5.3	28.8	11.4	7.0
Leaning (0.3)	6.1	19.8	11.3	7.8
SW rule				
Baseline	5.7	19.4	5.1	3.3
Leaning (0.1)	4.9	13.1	5.3	3.1
Leaning (0.3)	4.7	8.4	6.7	3.7
DIF rule				
Baseline	2.7	5.5	3.3	2.6
Leaning (0.1)	2.8	4.7	3.9	2.7
Leaning (0.3)	3.5	5.2	5.0	3.3

Notes: the loss function includes the variance of inflation and the variance of the output gap.

2. Thoroughly Test New Policy Rules or Interventions for Robustness

Robustness checks counteract the tendency to exploit special properties of models that may lead policy away from good rules. To maintain an effective policy operation in "rule-space" it is therefore important to establish the robustness of any new policy proposal. One should examine how new proposals for rules based on models with financial constraints will work in other models, and, conversely, consider the performance of traditional policy rules in newer models with financial factors.

A good example is again found in Wieland et al (2016). Table 3, drawn from their paper, shows several rules and their impact on performance. There are four model-specific rules and four other simple rules: the SW rule, the Taylor rule, a rule due to Orphanides and Wieland (2008) and an interest rate difference rule from Levin, Wieland, and Williams (2003). According to Table 3, the model specific rules work relatively well in the model they are designed for, but their performance is mixed in the other models. Some of the simple rules break down when financial factors are added, others are more robust. These examples give a taste of what is possible with new technologies to compare models.

Table 3: Policy Rules and their Robustness
Source: Wieland, Afanasyeva, Kuete, and Yoom (2016)

Model-specific rules	
DG08 rule	$i^z_t = 0.90 i^z_{t-1} + 0.23 p^z_t - 0.08 p^z_{t-1} + 1.14 q^z_t - 1.10 q^z_{t-1}$
IAC05 rule	$i^z_t = 0.73 i^z_{t-1} + 0.34 p^z_{t-1} + 0.14 y^z_{t-1}$
IN10 rule	$i^z_t = 0.60 i^z_{t-1} + 0.56 p^z_t + 0.82 y^z_t - 0.82 y^z_{t-1}$
CMR14 rule	$i^z_t = 0.85 i^z_{t-1} + 0.36 p^z_t + 0.05 y^z_t - 0.05 y^z_{t-1}$
Other simple rules	
Taylor rule	$i^z_t = 1.5\pi^z_t + 0.50 q^z_t$
SW rule	$i^z_t = 0.81 i^z_{t-1} + 0.39 p^z_t + 0.97 q^z_t - 0.90 q^z_{t-1}$
OW08 rule	$i^z_t = 2.34 E_t \pi^z_{t+3} + 0.765 E_t q^z_{t+3}$
DIF rule	$i^z_t = i^z_{t-1} + 0.5\pi^z_t + 0.5(q^z_t - q^z_{t-4})$

Note: The superscript z refers to common variables. i^z_t is the annualized short-term federal funds rate in quarter t. p^z_t refers to the annualized quarter-to-quarter rate of inflation, π^z_t is the year-on-year inflation rate, y^z_t is the deviation of quarterly real GDP from its long-run potential, while q^z_t refers to the output gap defined as the difference between actual GDP and the level of GDP that would be realized if prices and wages were flexible. All variables are expressed in percentage deviations from steady-state values.

	US_DG08	US_CMR14	US_IAC05	US_IN10	Average loss
Model-specific rule	5.8	47.6	12.3	6.9	–
CMR14 rule	9.1	47.6	20.4	3.0	20.0
Taylor rule	5.3	34.5	6.2	4.3	12.5
SW rule	5.7	19.6	5.1	3.3	8.3
OW08 rule	4.6	29.3	∞	3.0	∞
DIF rule	2.7	5.5	3.3	2.6	3.6

Notes: The loss function is the sum of the unconditional variances of inflation and output gap. ∞ indicates indeterminacy.

3. Design Models for Purpose of Evaluating Policy Rules

In general, thinking about the purpose of models helps keep research on track. In a paper entitled "Economic Theory, Model Size, and Model Purpose," (Taylor (1981) I showed that models used to find policy rules or tradeoff curves between output and inflation variability could be smaller than models used for forecasting and other purposes. Other models—perhaps variants on vector auto-regressions—could then be used for forecasting.

Thinking about monetary policy rule design and evaluation as objectives of model development also can lead to better outcomes. For example, Lepetyuk, Maliar and Maliar (2016) constructed a "Baby ToTEM" which they argued was well-suited for studying policies to deal with the effective lower bound and the impacts of a higher inflation rate.

4. Focus on the Interface Between Policy Rules and Actual Decisions

It is very important to find ways to relate actual policy decisions to research on policy rules. It is not an easy problem, and it pertains to all elements of public policy. Here some legislation in the United States Congress may provide some guidance. This policy rules legislation would require that Fed "describe the strategy or rule of the FOMC for the systematic quantitative adjustment" of policy instruments. This language was written into a bill which passed the U.S. House of Representatives in 2015. Clearly this legislation would provide a very transparent connection between policy analysis and policy decisions. It would be the central bank's job to choose strategy and how to describe it, but this would be connected to the research. Some worry that the central bank would lose independence, but I would argue that a visible connection between policy and economic analysis would improve independence.

You can think of this legislation as if the central bank would put its strategy in a transparent lockbox with the supposition that it would not be changed for several years. The central bank of course could change its strategy, but it would have to explain why. There are of course practical problems to deal with including uncertainty about the output gap, effective lower bound on the interest rate, or changes in the equilibrium real interest rate. But these problems are easier to deal with a rules-based environment.

There are other ways to deal with the interface. Charles Plosser and Jeff Lacker, who have had experience as policy makers at the Fed, have proposed that the Fed explain regularly how policy rules are used in making decisions. This too would make more transparent and effective the interface between research and policy. Weale (2016) has made similar suggestions for the Bank of England.

5. *Build Models So They Can Test Alternative Hypotheses about Monetary Policy*

Empirical models are a key way to test alternative theories about monetary policy, and they can be built with such tests in mind. For example, the Carney-King hypothesis that the tradeoff frontier moved in an adverse direction because of Minsky type effects should be tested more formally against the view in this paper that the problem was switching away from policy rules. New Keynesian models with financial constraints or financial accelerators could be used for this purpose, with both hypotheses nested in a single model.

Another example is testing whether deviations from rules-based policy have impacts abroad, and determining the sign of the impact. I have argued that deviations from rules based policy can have negative impacts abroad; some models confirm that and some do not. Raghu Rajan (2016) has proposed that monetary policy interventions be classified as Red, Yellow, or Green depending on whether they have negative, zero of positive impact abroad and that the international monetary system take that into account.

6. *Distinguish between Instrument Rules, Forecast Targeting, and Constrained Discretion*

The examples of policy rules I have mentioned thus far in this talk have been interest rate rules in which a contingency plan for the policy instrument is laid out. An alternative approach—called forecast targeting—does not entail a rule for the interest rate or any other policy instrument. Rather the central bankers set the interest rate in such a way that the forecasts of certain target variables move into alignment with their targets. Woodford (2012) has suggestively called this approach "Forecasting Targeting as a Monetary Policy Strategy." For example, the interest rate could be set so that the forecast at an horizon h is a linear combination of the deviation of the inflation rate (π) from its target (π^*) and the output gap (x) is expected to be on target as in this equation.

$$(\pi_{t+h,t} - \pi^*) + \phi x_{t+h,t} = 0$$

Forecast targeting has been studied and compared with interest rate rules. Questions about forecast targeting have been raised by Levin, Wieland and Williams (2003) including that the forecasts are generated by a single model and thus may not be robust or that it is difficult to explain. In any case any "rule-space" framework needs to distinguish between these two different approaches to policy.

Yet another alternative is called "constrained discretion' (Bernanke (2003)) where targets for the inflation rate or unemployment are specified, but the policymakers then do whatever they think is needed with the instruments to bring about these targets. In practice, constrained discretion is quite similar to a "path-space" approach where different paths of the instruments are simulated and their effects are traced out, but unlike forecast targeting there is no need for a formal modelling approach. While sometimes but forth as rules-based policy, the decision rule for policy completely open. Constrained discretion may be an appealing term, but it does not induce rules-based policy as the term suggests.

7. ***Think in Terms of a Rules-Based International Monetary System***:

Perhaps there is no more important, and no more difficult, application of "rule-space" analysis than the international monetary system. One workable research idea would simply be to expand the idea of rules-based policy in each country to the international system. In Taylor (2017b) I have proposed, for example, an international agreement in which each central bank would report and commit to its monetary rule or strategy, and thereby help build the foundation of the international monetary system. Clarida (2017) has developed this proposal further to deal explicitly with changes in the equilibrium real interest rate.

Models at central banks can be enormously helpful here. Indeed, multi-country models with rational expectations and price rigidities showed that a Nash equilibrium, in which each central bank followed its own rule, assuming that others did the same, led to an optimal outcome globally.

There is a lot of interest in international monetary reform. Paul Volcker (2014) noted that "the absence of an official, rules-based, cooperatively managed monetary system has not been a great success." Raghu Rajan (2016) added that "what we need are monetary rules that prevent a central bank's domestic mandate from trumping a country's international responsibility." Mario Draghi (2016) stated that "At one extreme, central banks can take global conditions as entirely exogenous and set their policies accordingly. At the other extreme is explicit coordination of monetary policies. In between is a range of informal solutions. So we would all clearly benefit from enhanced understanding among central banks on the relative paths of monetary policy. That comes down, above all, to improving communication over our reaction functions and policy frameworks."

Conclusion

In this talk I have reviewed the 80-year history of macro policy models and showed how policy analysis began in "path-space" and then moved on to "rule-space" with a paradigm shift 40 years ago. Central bank models followed these developments to the benefit of monetary policy and economic performance, though with a lag.

Recently there has been a retrogression in parts of the central banking world, and economic performance has deteriorated in the past decade. We need to get back to rule-space.

I proposed seven ideas for research with this purpose in mind, but all the recommendations are worthwhile pursuing even if one has different views of reasons for economic performance during the past decade. Perhaps the most powerful ideas focus on

- *the interface* between policy models and policy decisions,
- the *connection* between monetary policy rules and an international rules-based monetary system, and
- *robustness* through transparent and replicable macro model comparisons such as in the Macroeconomic Model Comparison Initiative using the Macro Model Data Base as I described with many examples in this talk.

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