The Role of Capital on Noise Shocks

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Preliminary

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Abstract

An important topic in recent macroeconomic literature is the potential effects of noise, or expectational, shocks on aggregates. Most of the past analysis has used some derivative of a New Keynesian model with labor as the only input, but doing so fails to consider that some input decisions may not have their returns realized today. To capture and explore this possibility under a noise shock framework, I incorporate endogenous capital accumulation in a New Keynesian model and solve for explicit dynamics using the method of undetermined coefficients. Results show that the qualitative predictions hold between my model and that without capital, but inclusion of capital significantly dampens the size of noise shocks: excluding capital raises the initial response of output to a noise shock by more than double. As usable capital on impact is fixed, labor responds less than the no-capital equivalent because it faces diminishing returns to scale. Coupling this effect with quasi-fixed capital accumulation leads to a muted output response in comparison to labor-only models. In addition, noise shocks are transient compared to a permanent shock. This is due to noise shocks being predominantly consumption driven opposed to investment driven. These results suggest that models without capital may overstate the significance of noise shocks.

*This paper is preliminary and is being extended and rewritten. Any mistakes in this draft are solely the fault of the author.

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1 Introduction

Agents in an economy use information to form beliefs that are used in decisions. Their decisions, in turn, in some way affect aggregates in the economy. How are different types of information interpreted by agents, and what sort of aggregate responses do these interpretations lead to? These questions have been at the heart of a large amount of recent economic literature, and an important subset of this literature is focused on the response of agents to noise, or expectational, shocks. Noise shocks can be seen as shocks only to an agent's expectations; they are shocks not driven by the fundamentals of the economy but are extrinsic to the system. The importance of noise shocks in aggregate fluctuations is debatable, and one must ask if results are overly dependent on model restrictions. A particularly large restriction is the absence of capital in the model. Opposed to labor, capital decisions made today do not affect current production. Therefore, agents cannot simply expand labor to meet demand; they now face decreasing returns in labor due to the fixed usable capital stock. This paper seeks to explore the differences capital leads to when under an environment subject to noise shocks.

I use a New Keynesian model based upon the example model in Lorenzoni [15], but incorporate endogenous capital. This model is a no-money economy with a representative household, sticky prices via Calvo [9] pricing, and a simple interest rate rule. Current productivity is made up of a temporary and permanent component and is observed by all agents. However, the permanent component follows a unit root process and is *not* observable. The household receives an imperfect signal and uses this signal to create expectations about permanent productivity. When I shock this signal, without changing the underlying permanent productivity, I produce a noise shock as it only affects expectations. I first look at the response agents have to a permanent productivity shock and then how they respond to a noise shock. I then compare these responses to the equivalent model where production relies only on labor and apply some sensitivity analysis.

In my benchmark parameterization, a positive permanent shock leads to the same directional movement in aggregates between the capital and no capital model, but the rate of convergence is considerably more sluggish in the model with capital. Output, consumption, and capital all increase but respond less than the true underlying productivity would suggest in the perfect information equivalent. Capital accumulation responds slowly to the shock, but this is largely due to the gradual nature of investment rather than imperfect information. In fact, removing the noise in agent's expectations makes a practically insignificant difference in the rate of accumulation. Slow capital accumulation in turn leads to slow convergence to the new balanced growth path which takes nearly three times as long as its no capital equivalent. The prolonged capital accumulation gives some prediction as to what we may expect to happen when a noise shock is applied to the economy. If informational frictions lead to no significant change in the accumulation of capital under a permanent shock, then what could one expect when we only shock the noise of this friction?

A noise shock leads to positive responses in all the aggregates in both capital and no-capital models. Consumption, inflation, output, investment, etc. all increase on impact and slowly return to previous levels. Positive output responses from a noise shock occur through two vehicles: the household's Euler equations and sticky prices. Nominal rigidities cause the real interest rate to react more slowly than it would in the case of flexible prices. Through the bond Euler, current consumption–and thus output–depends positively on future expected output and responds negatively to the real interest rate. As expectations increase about the underlying permanent productivity (a good indicator of future productivity), expected output becomes higher. With nominal rigidities, the real rate responds slowly, otherwise it would respond in such a way to completely mitigate any changes in expectations. Between the real rate's slow response and the increased expectations of future output and consumption, current output increases leading to many other aggregates following suit.[1] Output is predominantly driven by an increased consumption response; investment responds weakly when not reinforced with observed productivity increasing. As capital makes up a large proportion of production ($\alpha = .34$ in a Cobb-Douglas production function), and this factor is essentially fixed due to its minimal response, labor faces diminishing returns to scale. Diminishing returns causes agents to supply less labor than they would have if they faced constant returns as in previous models.[2] My benchmark model's lackluster capital response to a noise shock then leads to a weak output response.

On impact, a noise shock in the model without capital causes a response in output that is more than double my benchmark. On the other hand, because an capital stock has increased and it's costly to adjust (the household faces convex adjustment costs), the persistence of a noise shock is more significant in the model with capital. The level it persists at, however, is very small. Taking these two facts into account, and doing some sensitivity analysis, I conclude that it is likely that models without capital overestimate the scale of responses to a noise shock. In alternative models with only labor, my results should carry over, and we would expect the model's economy to have less volatility resulting from noise shocks if they

[1] Greater detail on the phenomenon, especially the role of nominal rigidities, can be found in Lorenzoni [15] and Barsky [4].

[2] Khan and Thomas [14] briefly discussed this property under a model with inventories.

were to include capital.

My model is based off of Lorenzoni [15] wherein he uses the labor-only version as an example to build intuition of his full-fledged model of dispersed information. His model of dispersed information also contains labor-only production, but with significant information frictions he finds that noise can potentially account for a sizable amount of volatility. He uses his simple model as an explanation of what mechanism is at play in his more opaque model. By this logic, the results found in my model should carry over if I impose a similar framework. A version of his model was also applied more recently in Blanchard et al.[8], and they find that noise shocks play a significant role in short-run fluctuations using a structural parametrization of their model. Angeletos and La'O [1],[2] have also explored the role and implications of noise shocks using a model comparable to Lorenzoni's example model.

News shocks, as in Beaudry and Portier [5], [6], are related to noise shocks but should be differentiated. In particular, the idea of news shocks involves actual information about future productivity. On the other hand, noise shocks are completely extraneous to the economy.

A more recent paper by Barsky and Sims [4] also included endogenous capital along with habit. However, this paper was largely concerned on the impact of news vs. noise on confidence innovations and how these innovations lead to aggregate fluctuations. They find that noise does *not* seem to play a significant role in aggregate fluctuations. The only way that it can is through essentially raising nominal rigidities to unrealistic amounts. My paper, instead, looks specifically at the role of capital in models of noise shocks. It does not contain complicating factors such as habit or complex interest rate rules because I wanted it to be a clean exercise. In doing so, we can explicitly see what capital may do in comparable models (including Barsky and Sims [4]), and get a better understanding of the role of capital.

The concept of noise shocks owes its origins to initial thinkers such as Keynes who dubbed them "animal spirits". It was more formally developed later in the works of Phelps et al. [20] and Lucas [16] in the form of expectational errors. The existence of "animal spirits" also gained further exposure in the 1990-1991 recession where discussions such as Blanchard [7] believed some sentiment outside of the system caused agents to respond in a way that curbed consumption.

Other related papers include alternative theories of information restrictions which include: sticky information introduced by Mankiw and Reis [17] and rational inattention as in Sims [21] and more recently developed in Maćkowiak and Wiederholt [18]. Work has also been done on the welfare consequences of imperfect information in the works of Morris and Shin [19] and Angeletos and Pavan [3].

Section 2 of my paper explains the model and discusses the learning process. Section 3 details calibration, methodology, and my solution. I then analyze a positive permanent productivity shock and a positive noise shock to my model and discuss the intuition for the observed responses. In Section 4, I compare my benchmark model with the model without capital and further elaborate on the role of capital. Section 5 has a very brief discussion of possible extensions, and Section 6 concludes the paper.

2 The Model

I use a New Keynesian model with a representative household and Calvo [9] pricing. It is largely based off of the simple model presented in Lorenzoni [15] with the principle differences being capital and convex adjustment costs. The model's technology process requires me to detrend the model. As such, it is more intuitive to first introduce the technology and shock process.

2.1 Technology

The representative household will consume a composite good, C_t, that is composed of a unit mass of intermediate goods, each indexed by $j \in [0, 1]$. C_t is created by a competitive final good firm that chooses inputs to minimize costs and meet demand of the household. Intermediate good firm j produces according to:

$$Y_{j,t} = A_t^{1-\alpha} K_{j,t}^{\alpha} N_{j,t}^{1-\alpha} \tag{1}$$

A_t is a labor-augmenting technology process and is defined as:

$$A_t = X_t exp(\eta_t) \tag{2}$$

Current technology is composed of a temporary component, η_t, distributed iid $N(0, \sigma_\eta^2)$ and a permanent component, X_t, defined as:

$$X_t = X_{t-1} exp(\epsilon_t) \tag{3}$$

The permanent component is a unit root process with ϵ_t being distributed iid $N(0, \sigma_\epsilon^2)$. The household and firms can observe A_t but not X_t. Therefore to induce stationarity, we must detrend by the observable variable A_t. The process by which households form expectations about the permanent component will be discussed later in the paper. I define $\tilde{A}_t$ as:

$$\tilde{A}_t = \frac{A_t}{A_{t-1}} = \frac{X_t}{A_{t-1}} exp(\eta_t) = \tilde{X}_t exp(\eta_t) \tag{4}$$

$$\text{where } \tilde{X}_t = \frac{X_t}{A_{t-1}} exp(\epsilon_t) = exp(\epsilon_t - \eta_{t-1}) \tag{5}$$

Let any variable with a tilde above it represent the detrended version of the original variable (e.g. $\tilde{Y}_t = \frac{Y_t}{A_{t-1}}$). I will now present the detrended model.

2.2 Representative Household

There is a infinitely-lived, representative household that maximizes their sum of expected discounted utility.

$$E_t \sum_{t=0}^{\infty} \beta^t [ln(\tilde{C}_t) - \frac{\omega}{1+\varsigma} N_t^{1+\varsigma}] \tag{6}$$

Where β is the discount factor, ω the level of disutility of labor, ς the inverse of the Frisch elasticity of labor, and N_t are hours worked. Maximizing the above is subject to a budget constraint and no-ponzi condition.

$$P_t \tilde{C}_t + Q_t \tilde{B}_{t+1} \tilde{A}_t + P_t \tilde{I}_t = \tilde{B}_t + \tilde{W}_t N_t + R_t^k \tilde{K}_t + \int_0^1 \tilde{\Pi}_{j,t} dj \tag{7}$$

$$lim_{T \to \infty} \beta^T \tilde{B}_T = 0 \tag{8}$$

$$\text{Where } \tilde{\Pi}_{j,t} = (P_{j,t} \tilde{Y}_{j,t} - R_t^k \tilde{K}_{j,t} - \tilde{W}_t N_{j,t})$$

Q_t is the nominal price of one-period bonds B at time t, W_t nominal wage at time t, P_t aggregate price index at time t, $P_{j,t}$ price set by firm j at time t, and R_t^k is the nominal rental rate of capital at time t. The price index is defined as:

$$P_t = (\int_0^1 P_{j,t}^{1-\gamma} dj)^{\frac{1}{(1-\gamma)}} \tag{9}$$

Where γ is the elasticity of substitution between intermediates. Capital accumulation evolves according to:

$$\tilde{I}_t = \tilde{K}_{t+1} \tilde{A}_t - (1-\delta) \tilde{K}_t + \frac{\phi}{2} \frac{(\tilde{K}_{t+1} \tilde{A}_t - \tilde{K}_t)^2}{\tilde{K}_t} \tag{10}$$

Any changes in the capital stock faces a convex adjustment cost with level of costs determined by ϕ.[3] Capital stock chosen today, $\tilde{K}_{t+1}$, is not utilized in production until period $t+1$ and its choice is based on the expected return of capital in period $t+1$.

2.3 Firm's Problem

Through the final good firm's optimality condition, we get the following demand for intermediates:

$$Y_{j,t} = (\frac{P_{j,t}}{P_t})^{-\gamma} Y_t \tag{11}$$

Where Y_t is output of the final good firm.

Intermediate good firm j faces Calvo-pricing and can adjust its price in a given period with probability $1-\theta$, otherwise it maintains its previous period's price. If intermediate firm j is able to change its price, it does so to maximize:

$$E_t \sum_{\tau=0}^{\infty} \theta^{\tau} \tilde{Q}_{t,t+\tau|t}[P_{j,t+\tau} Y_{j,t+\tau} - W_{t+\tau} N_{j,t+\tau} - R^k_{t+\tau} K_{j,t+\tau}] \tag{12}$$

s.t. $P_{j,t+\tau} = P^*_t$, which is the optimal price at time t, (1), and (11)

$\tilde{Q}_{t+\tau|t}$ is the stochastic discount factor and is defined as $\tilde{Q}_{t+\tau|t} = \beta^{\tau}(\frac{C_{t+\tau}}{C_t})^{-1} A^{-1}_{\tau-1}$. This, along with wage, rental rate of capital, and P_t, are taken as given by the firm. A given intermediate good firm also minimizes real costs in every period:

$$min_{N_{j,t},K_{j,t}} \{\frac{W_t}{P_t} N_{j,t} + \frac{R^k_t}{P_t} K_{j,t}\} \tag{13}$$

subject to equations (1) and (11).

2.4 Monetary Authority

Following Lorenzoni [15], the interest rule is relatively simple. This was chosen to make the exercise as clean-cut as possible without other factors heavily influencing responses to noise shocks.[4] Let $R_t = \frac{1}{Q_t}$ denote the nominal interest rate. Then monetary policy follows a

[3] Convex adjustment costs were added as a necessity to guarantee determinacy in a New Keynesian model with endogenous capital. More details can be found in Dupor [12] and Section 4.

[4] Noise shocks, as will be seen, depend on the real rate being below the level of expectations. Having a Taylor rule that's responsive to output dampens the overall impact of noise shocks.

simple Taylor rule:

$$R_t = \frac{1}{\beta}(\frac{P_t}{P_{t-1}})^{\nu} \tag{14}$$

ν is chosen by the monetary authority. In general, I assume that $\nu > 1$, implying the monetary authority has an active interest rate rule.

2.5 Aggregation

It can be shown that aggregate production follows the following process:

$$\tilde{Y}_t = \tilde{A}_t^{1-\alpha} N_t^{1-\alpha} \tilde{K}_t^{\alpha} \tag{15}$$

Also, final goods market clearing must satisfy:

$$\tilde{Y}_t = \tilde{I}_t + \tilde{C}_t \tag{16}$$

2.6 Linearization

Given our household problem and firm's problem, I solve for the optimality conditions. Detrending the resulting optimality conditions if necessary, I then solve for the balanced growth path (BGP) and log-linearize the set of all equations that fully specify equilibrium dynamics in my economy.[5]

Let an uncapitalized letter with a tilde represent the percent deviation from the BGP of a detrended variable (e.g. $\tilde{c}_t = ln(\frac{C_t}{A_{t-1}}) - ln(\tilde{C})$). Likewise, let an uncapitalized letter without a tilde represents the percent deviation from the BGP of an already stationary variable.

Combining the household labor-leisure condition and consumption decision yields:

$$\tilde{c}_t + \varsigma n_t = \hat{w}_t \tag{17}$$

Where $\hat{w}_t = \tilde{w}_t - p_t$ is the detrended real wage. Define $\pi_t = p_t - p_{t-1}$ as inflation. Taking the consumption optimality condition and combining it with optimal bond holdings creates the bond Euler equation:

$$\tilde{c}_t = E_t\{\tilde{c}_{t+1}\} - r_t + E_t\{\pi_{t+1}\} + \tilde{a}_t \tag{18}$$

[5] Solving the BGP was trivial, so it will not be presented in the paper. Calculations are available upon request.

Combining consumption optimality and optimal capital holdings results in the capital Euler equation:

$$\tilde{c}_t = E_t\{\tilde{c}_{t+1}\} - (1-\beta(1-\delta))E_t\{\hat{r}^k_{t+1}\} - \phi\tilde{k}_t + (1+\beta)\phi\tilde{k}_{t+1} - \beta\phi E_t\{\tilde{k}_{t+2}\} + (1+\phi)\tilde{a}_t - \beta\phi E_t\{\tilde{a}_{t+1}\} \tag{19}$$

Let $\hat{r}^k_t = r^k_t - p_t$ and note that, unlike wages, this variable is stationary and does not require detrending.

We can see in (18) and (19) how current consumption (and consequentially output) depends positively on expectations of future consumption, but negatively on the real interest rate, $r_t - E_t\{\pi_{t+1}\}$.[6] As will be discussed shortly, it is through these two equations that expectational shocks are able to affect output, consumption, and investment.

A standard result under Calvo-pricing is that, taking the firm's optimal pricing condition, the aggregate evolution of prices, and properly detrending, one can acquire the following forward-looking New Keynesian Phillips curve:

$$\pi_t = \beta E_t\{\pi_{t+1}\} + \Omega(\alpha\hat{r}^k_t + (1-\alpha)\hat{w}_t - (1-\alpha)\tilde{a}_t) \tag{20}$$

$$\text{where } \Omega \equiv \frac{(1-\theta)(1-\beta)}{\theta} \tag{21}$$

Log-linearizing capital accumulation:

$$\delta\tilde{i}_t = \tilde{k}_{t+1} - (1-\delta)\tilde{k}_t + \tilde{a}_t \tag{22}$$

Log-linearizing monetary policy:

$$r_t = \nu\pi_t \tag{23}$$

Therefore, given $\nu > 1$, the real interest rate responds greater than one in response to inflation.

Using the final goods condition (16) and log-linearizing yields the standard result:

$$\tilde{y}_t = \frac{\tilde{C}}{\tilde{Y}}\tilde{c}_t + \frac{\tilde{I}}{\tilde{Y}}\tilde{i}_t \tag{24}$$

Solving the aggregate firm's cost minimization problem and log-linearizing yields aggregate input demand:

$$n_t + \hat{w}_t = \hat{r}^k_t + \tilde{k}_t \tag{25}$$

[6]Current consumption also depends negatively on expected future returns to capital.

Lastly, I log-linearize the aggregate production function:

$$\tilde{y}_t = (1-\alpha)\tilde{a}_t + \alpha\tilde{k}_t + (1-\alpha)n_t \tag{26}$$

Equations (17)-(26) fully specify the equilibrium dynamics of my economy. I must now take into account that current output and pricing decisions depend on expectations of future productivity. A good indicator of future productivity would be the underlying permanent component of technology, X_t, but this is unobservable to the household. The household therefore faces a signal extraction problem and must infer the underlying permanent productivity process, and they do so with the addition of a signal and using a Kalman filtering process.

3 Learning and Signals

Log-linearizing our detrended productivity process (4) and (5), and noting that $ln(\tilde{X}) = ln(\tilde{A}) = 0$ in the BGP, gives us the following set of equations

$$\tilde{a}_t = \tilde{x}_t + \eta_t \tag{27}$$

$$\tilde{x}_t = \epsilon_t - \eta_{t-1} \tag{28}$$

The temporary shock, η_t, makes it so that the household cannot directly determine the underlying permanent productivity process; what they observe may not be due to a change in permanent productivity but merely a one-period shock. To help facilitate noise shocks, the parameterized variance of η_t will be large relative to other variances to complicate the signal extraction problem.

The household observes $\tilde{a}_t$ but not $\tilde{x}_t$. With only $\tilde{a}_t$, the household is unable to learn effectively. Therefore, they also receive a signal about the permanent component. A real-world example would be an announced estimate of last period GDP. However, as is established in Faust et al.[13], these estimates can be subject to significant errors.[7] These errors give rise to noise/expectational shocks. Explicitly, the household receives:

$$\tilde{s}_t = \tilde{x}_t + e_t \tag{29}$$

[7]Faust et al. [13] found that quarterly growth rate revisions in G-7 nations were commonly more than one percentage point, annualized. Furthermore, they find that this forecasting error is generally unpredictable.

Where e_t is distributed iid $N(0, \sigma_e^2)$. A shock to the e_t term embodies an expectational shock: a shock affecting only beliefs, not the fundamentals. The household then forms beliefs about the underlying permanent productivity using Kalman filtering. Let $\tilde{x}_{t|t} = E_t\{ln(X_t)\} - ln(A_{t-1})$ define the expectations at time t of the detrended productivity process. It can be shown that these expectations evolve according to:[8]

$$\tilde{x}_{t|t} = \rho(\tilde{x}_{t-1|t-1} - \tilde{a}_{t-1}) + (1-\rho)(\chi\tilde{s}_t + (1-\chi)\tilde{a}_t) \tag{30}$$

$$\text{where } \rho = \frac{\frac{1}{\sigma_x^2}}{\frac{1}{\sigma_x^2}+\frac{1}{\sigma_e^2}+\frac{1}{\sigma_\eta^2}} \text{ and } \chi = \frac{\frac{1}{\sigma_e^2}}{\frac{1}{\sigma_\eta^2}+\frac{1}{\sigma_e^2}}$$

One peculiarity to mention is that the response of expectations to noise shocks varies non-monotonically with the variance of e_t. This is because at low variances the signal is too precise and therefore there is little effect. At higher variances it is too imprecise, which causes the weight on the signal $((1-\rho)\chi)$ to be too low for the household to respond.[9]

4 Results

Given an explicit evolution of expectations (30), my system of dynamic equations (17)-(26), and calibration/parameterization, I proceed by solving for explicit dynamics using the method of undetermined coefficients. Acquiring values for impulse responses of the detrended/log-linearized aggregates, I convert them to levels and then percentage deviations from prior to shock levels for both permanent technology and noise shocks.[10]

4.1 Calibration/Parameterization

The model is a quarterly model. $\beta = .99$ is set to imply an annual real interest rate of .04. I then choose δ so that annual $\frac{I}{K}$ is equal to .088 in the BGP. $\alpha = .34$ implies that the percentage of labor income is about 66%. The elasticity of substitution, γ, is 9.5 and was chosen such that $\frac{K}{Y} = 2.37$ annually along the BGP. This value also implies that BGP firm markup above MC is about 12%. I set $\omega = 4$, resulting in BGP labor supply of .33.

The ϕ parameter was set to 6. At low levels of ϕ, investment responds *negatively* to a noise shock. This is in fact true for a value of 3. According to the literature, if anything, a

[8] Using standard Kalman filtering techniques and a little bit of algebra achieves this result.

[9] More detail can be found in Lorenzoni [15].

[10] I decided to not look at temporary shocks, η_t, as they're largely extraneous for the purpose of the paper. If one wishes to view the impulse responses, they're available upon request.

Table 1: Parameter Values			
β	.99	δ	.022
α	.34	γ	9.5
ω	4	ϕ	6
ς	.5	ν	1.5
θ	$\frac{2}{3}$	σ_η	.15
σ_ϵ	.0077	σ_e	.03

noise shock should result in a positive investment response because, as we'll see, it acts as a classical demand shock: increasing prices, output, labor, consumption, etc. I then decided on a value of 6 which indeed results in a positive investment response, though I do undertake some sensitivity analysis of ϕ later in the paper. The remaining parameters are set using values used by Lorenzoni. [15].[11] The Frisch elasticity of labor parameter, ς, was set to .5. The parameter on the monetary authority's response to inflation, ν, was set to 1.5. Next, θ–the Calvo-pricing parameter–is set to $\frac{2}{3}$, such that the average price duration is 9 months. Variances of the shocks were chosen such that the signal extraction problem is relatively difficult for individuals. A summary of them and other parameters can be seen in Table (1). Notice that the standard deviation (SD) of the temporary shock, σ_η, is nearly 20 times larger than the SD of the permanent technology shock and five times larger than the SD of the noise shock. As mentioned previously, this complicates the signal extraction problem to help give rise to meaningful responses from noise shocks.

Next, given the variances for all the shocks, one can solve for σ_x as the resulting positive solution to the following Ricatti equation:

$$(\sigma_e^2 + \sigma_\eta^2)(\sigma_x^2)^2 - (\sigma_\epsilon^2\sigma_e^2 + \sigma_\epsilon^2\sigma_\eta^2)\sigma_x^2 - (\sigma_\eta^2\sigma_e^2\sigma_\epsilon^2) = 0$$

The solution results in the value of .0152 for σ_x. This parameter, in conjunction with the parameters in Table (1), itemize all provided variables of the model. We can now move forward to solving the model.

4.2 Method of Undetermined Coefficients

A large benefit of using the method of undetermined coefficients is that one can see vividly how changes in the state variables translate to changes in endogenous variables. Given that this paper is more of an expositional exploration of the effect of capital on noise shocks, this solution method provides a nice avenue for intuition.

[11]Lorenzoni [15] chose these parameter values to give noise shocks a strong possibility to have significant effects and persistence. By the same token, I wish to give noise shocks a ripe environment to flourish.

4.3 Methodology

In this model, the state variables at time t are $\tilde{x}_{t|t}$, $\tilde{a}_t$, and $\tilde{k}_t$. Given these variables, I then make a conjectures as to the evolution of detrended output and capital, as well as inflation:

$$\pi_t = \psi_{\pi k}\tilde{k}_t + \psi_{\pi a}\tilde{a}_t + \psi_{\pi x}\tilde{x}_{t|t} \tag{31}$$

$$\tilde{y}_t = \psi_{yk}\tilde{k}_t + \psi_{ya}\tilde{a}_t + \psi_{yx}\tilde{x}_{t|t} \tag{32}$$

$$\tilde{k}_{t+1} = \psi_{kk}\tilde{k}_t + \psi_{ka}\tilde{a}_t + \psi_{kx}\tilde{x}_{t|t} \tag{33}$$

Denote ψ as the $[9 \times 1]$ vector of the above ψs, of which the ordering does not matter for my purposes.

Using equations (17)-(20) and (22)-(26), I reduce the system of nine equations to three equations. Doing so results in a system of state, current choice, and future expectation variables. Given this set of equations, I then plug in conjectures (31)-(33) to try and create a system of only the state variables to solve for ψ. As can be seen from the Euler equations, this implies that I have to plug in one-period ahead conjectures. That is, my final equations contain $E_t\{\tilde{y}_{t+1}\}$, $E_t\{\tilde{k}_{t+2}\}$, and $E_t\{\pi_{t+1}\}$, which I then replace as follows:

$$E_t\{\pi_{t+1}\} = \psi_{\pi k}\tilde{k}_{t+1} + \psi_{\pi a}E_t\{\tilde{a}_{t+1}\} + \psi_{\pi x}\tilde{x}_{t+1|t} \tag{34}$$

$$E_t\{\tilde{y}_{t+1}\} = \psi_{yk}\tilde{k}_{t+1} + \psi_{ya}E_t\{\tilde{a}_{t+1}\} + \psi_{yx}\tilde{x}_{t+1|t} \tag{35}$$

$$E_t\{\tilde{k}_{t+2}\} = \psi_{kk}\tilde{k}_{t+1} + \psi_{ka}E_t\{\tilde{a}_{t+1}\} + \psi_{kx}\tilde{x}_{t+1|t} \tag{36}$$

At this stage, I still run into an issue. My system now contains period-ahead forecasts of state variables (and still an endogenous variable remains). Focusing first on the period-ahead forecasts, because of the specification of technology, I am able to bring back expectations of these future variables to today. It can be shown:[12]

$$E_t\{\tilde{a}_{t+1}\} = \tilde{x}_{t+1|t} = \tilde{x}_{t|t} - \tilde{a}_t \tag{37}$$

Therefore, we can replace any step-ahead expectations of future productivity and permanent productivity by equation (37), effectively reducing them to today's state variables.

The next issue is that I still have have an endogenous variable ($\tilde{k}_{t+1}$). I deal with this by

[12]For example, $E_t\{\tilde{a}_{t+1}\} = E_t\{x_{t+1} - x_t + \eta_{t+1} - \eta_t\} = -E_t\{\eta_t\}$ by the fact that x_t follows a unit root process. Then $-E_t\{\eta_t\} = x_{t|t} - a_t = \tilde{x}_{t|t} - \tilde{a}_t$. The proof for $\tilde{x}_{t+1|t}$ is similar.

simply once again substituting it with conjecture (33). A reader may notice that doing so will result in a ψ_{kk}^2 in my system. This means that I will have two possible solutions.

Making the above adjustments to my original system of three equations, I get a system composed of only constants–determined and undetermined–and current state variables. For an arbitrary individual equation in my original system of three, I can rearrange terms such that the following holds true:

$$A'\psi\tilde{x}_{t|t} + B'\psi\tilde{y}_t + C'\psi\tilde{k}_t = 0 \tag{38}$$

Where A, B, and C are $[9 \times 1]$ vectors composed of parameter values (and potentially ψ_{kk}). Given my model's assumptions, for (38) to be true it must be that:

$$A'\psi = B'\psi = C'\psi = 0 \tag{39}$$

From this, one can see how three equations are derived from one of my original system of equations. Doing this for all three of my equations in the system yields nine equations and nine unknowns whose solution is the vector ψ such that the equivalent of (39) is satisfied for all nine equations.

4.4 Solution

To tackle the issue of a nonlinear set of equations, I simply solve the model numerically.[13] As for the issue of duplicity, only one vector ψ resulted in reasonable responses.[14] Acquiring ψ, I can then use (31)-(33) to see how changes in the state variables translate to endogenous choice. Doing so results in:

$$\pi_t = -.028\tilde{k}_t - .126\tilde{a}_t + .153\tilde{x}_{t|t} \tag{40}$$

$$\tilde{y}_t = .25\tilde{k}_t + .445\tilde{a}_t + .306\tilde{x}_{t|t} \tag{41}$$

$$\tilde{k}_{t+1} = .967\tilde{k}_t - .97\tilde{a}_t + .003\tilde{x}_{t|t} \tag{42}$$

How can we interpret these numbers? At a glance, they may seem a bit counterintuitive, but then we must remind ourselves that these are detrended variables. For instance, when looking at $\tilde{k}_{t+1}$ in (42), note that this is $ln(\frac{K_{t+1}}{A_t}) - ln(\tilde{K})$. Therefore, the fact that it responds

[13] A great resource for the undetermined coefficient solution methodology can be found in Christiano [10]
[14] The other led to divergent behavior with no return to a BGP.

negatively to $\tilde{a}_t$ is clearly the result of detrending. If we were to expand the variables and do some cancelations, we would get the following more intuitive form:

$$ln(K_{t+1}) - ln(\tilde{K}) = .03ln(A_t) + .967(ln(K_t) - ln(\tilde{K})) + .003ln(X_{t|t}) \tag{43}$$

These equations represent what would happen in my model even under perfect information. With perfect information, I would have $X_{t|t} = X_t$. Notice the very weak response to expectations, which gives us some intuition as to what we can expect when this economy faces a noise shock that only affects expectations. Also, if we were to have a true permanent technology shock that increases a_t and x_t in my benchmark, we would indeed expect a positive response to capital, but a response that is less than what the true level of productivity would dictate as expectations lag behind the true permanent productivity.

Fortunately, (40) and (41) maintain their general intuition due to the fact that they're detrended by A_{t-1} and therefore any change of A_t is only reflected in the right hand side of the equation. We can see output, (41), responds strongly to expectations about the permanent productivity and to current productivity. The reason for the strong response to current productivity is clear. Why then does output respond positively to expectations? The answer is through the household's bond and capital Euler equations, (18) and (19). If one substitutes consumption in these equations with (24), then one sees that current output depends positively on expectations of future output. The best judge for future output is one's expectations of the underlying permanent productivity process and it's through this that positive expectations lead to positive output responses.

Taking the relatively large output response to expectations in conjunction with a weaker capital response–as seen in (43)–we can then expect any output response to noise shocks must be largely consumption driven as investment responds only weakly.

From (40), inflation can be seen as responding to a sort of output gap between the underlying permanent productivity and the natural output directed by A_t. If expectations are high compared to current productivity, the household responds positively in current output through their Euler equations; more so than what the current level of productivity would entail. This in turn causes firms to face higher real marginal costs and leads them to increase prices. The opposite would hold true if expectations lagged behind current productivity.

Using (40)-(42) with (17)-(26), I can now fully characterize the equilibrium dynamics of my complete economy when exposed to a shock at time t. However, to ease intuition in future sections, I convert these detrended/log-linearized values into levels and then to percentage deviation from previous level values. I convert detrended variables to levels with the following equation, letting F_t be the level of some arbitrary variable at time t that's detrended:

$$F_t = (\tilde{f}_t F + F)A_{t-1} \tag{44}$$

Where F is some predetermined level.

4.5 Response to Permanent Technology Shocks

To have an explicit value for the pre-shock level of variables, I must make an assumption on A_{t-1} and X_{t-1}. Without loss of generality, I assume the value of these variables is 1 and that the economy is on the BGP at time $t-1$ and has been on the BGP since at least $t-3$. For my future exposition I will assume $t = 3$. In other words, in all my analysis henceforth, I assume the shock occurs in period 3, and the economy was on the BGP in periods $t = 0, 1, 2$.

I apply a positive shock of $\epsilon_t = .01$ at $t = 3$, a 1% shock to permanent TFP. This results in $\tilde{x}_3 = \tilde{s}_3 = \tilde{a}_3 = .01$. However, expectations do not fully respond to this increase. Using equation (30), we can find the evolution of $\tilde{x}_{3|3}$ given the above and noticing $\tilde{x}_4 = \tilde{s}_4 = \tilde{a}_4 = 0$:

$$\tilde{x}_{3|3} = (1-\rho)(.01) \tag{45}$$

$$\tilde{x}_{3+t|3+t} = -(\rho)^{t+1}(.01) \text{ where } t > 0 \tag{46}$$

Using the value of the productivity shock and (45)-(46), I am able to derive impulse responses using equations (40)-(42) and (17)-(26). I then convert the responses into levels using (44) and compute percentage deviation from pre-shock levels. The resulting impulse responses for a permanent technology shock can be seen in Figure 1.

First, one can immediately notice that output only gradually reaches the level that would be implied by the actual productivity level. The slow output response is largely the consequence of typically gradual capital accumulation and not the signal extraction problem itself. I will elaborate and support this point further in the next section. We can see that most other aggregates have relatively strong initial responses, but capital responds sluggishly and continues to do so for the remaining periods, translating to the observed output response.

As the household initially increases capital far below its natural levels, initial responses in output are not factor driven but technology driven. The household initially decreases the amount of labor they supply. At the same time, wages and the rental rate of capital respond less than what productivity would suggest, implying–through the New Keynesian Philips

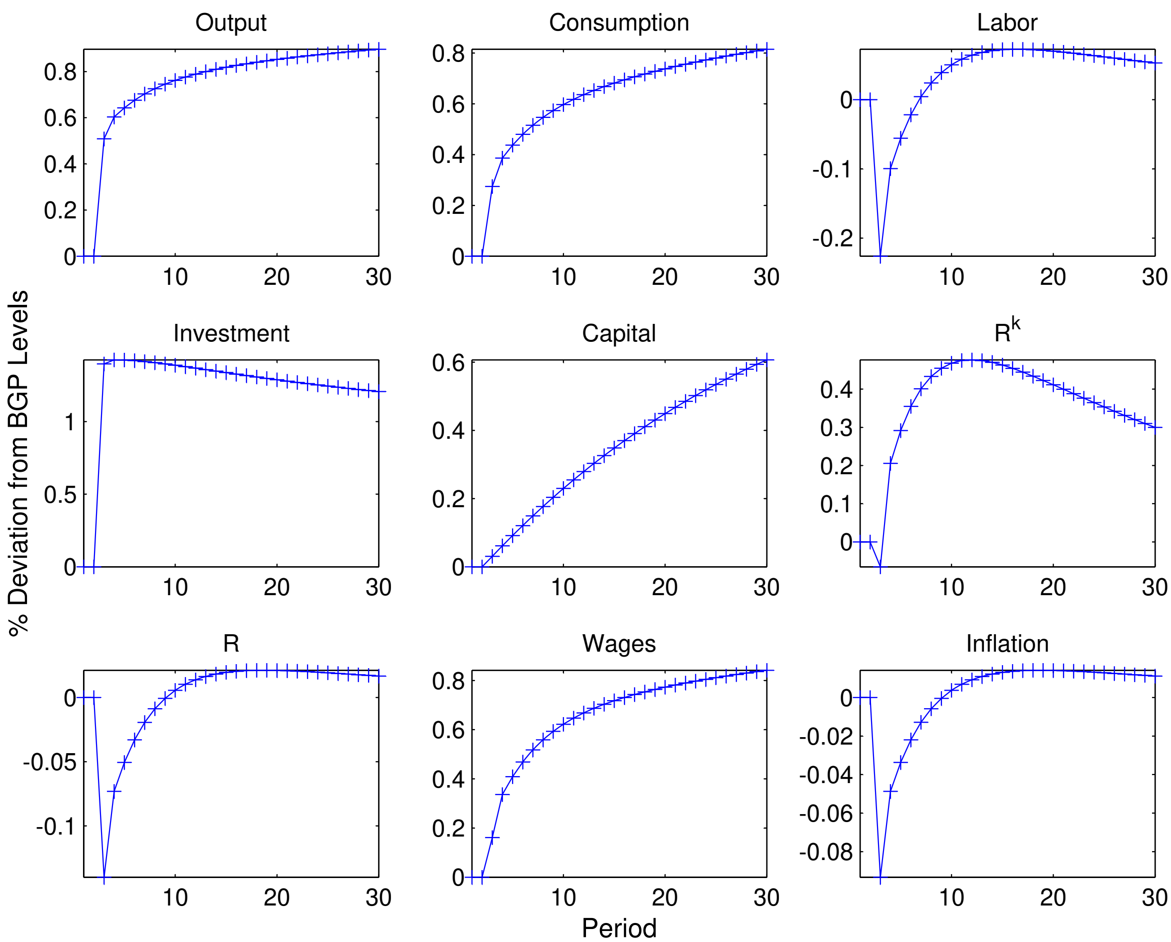

Figure 1: Impulse responses to a .01 permanent technology shock. The x-axes are quarter periods and the y-axes are percentage deviation from previous levels (e.g. .1=.1% difference).

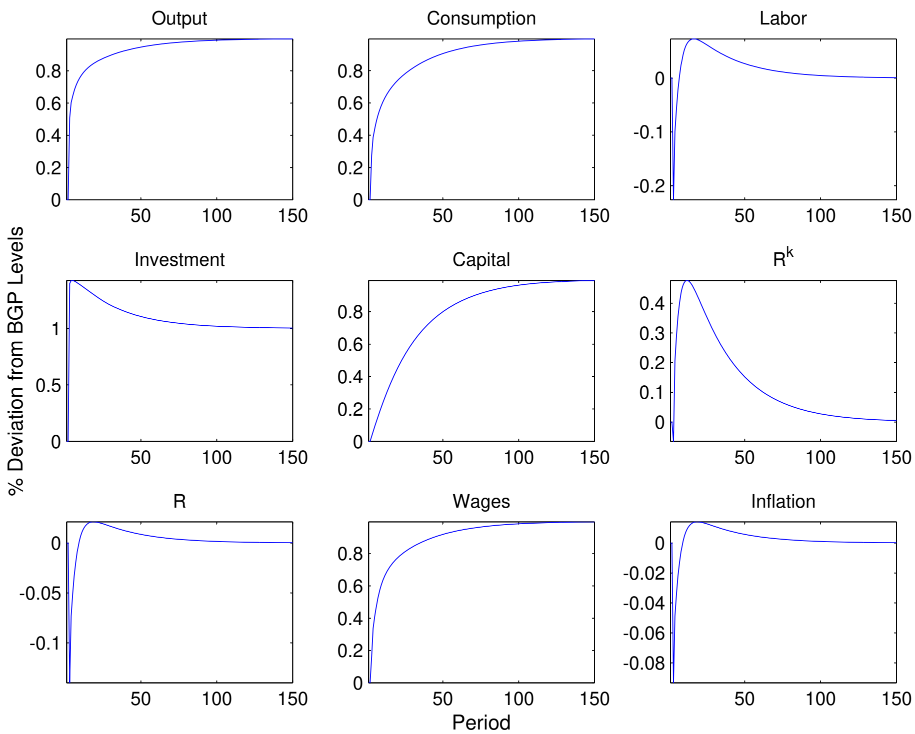

Figure 2: The same impulse responses as Figure (1), but the x-axis has been expanded to 150 periods.

curve–that firms first respond with a decrease in their prices. Firms respond as such due to marginal costs lagging behind the additional output a firm has from improved technology. Eventually, however, capital accumulation begins to lag behind the level of output desired and wages have increased such that agents decide to contribute more labor. This increase in labor and sluggish capital accumulation leads to a rapidly increasing marginal product of capital and consequentially high rental rate of capital, R^k. The abnormally high rental rate coupled with increasing wages, eventually leads price-changing firms to increase their prices, resulting in positive inflation. As the capital shortage is alleviated and labor supply decreases, the rental rate of capital begins to deflate, and inflation returns to its steady-state level.

The effects of a positive shocks are impressively persistent. Figure 2 shows that it takes roughly 120 periods until output converges to its new BGP. Again, this is due to the nature of capital adjustment in the face of convex adjustment costs.

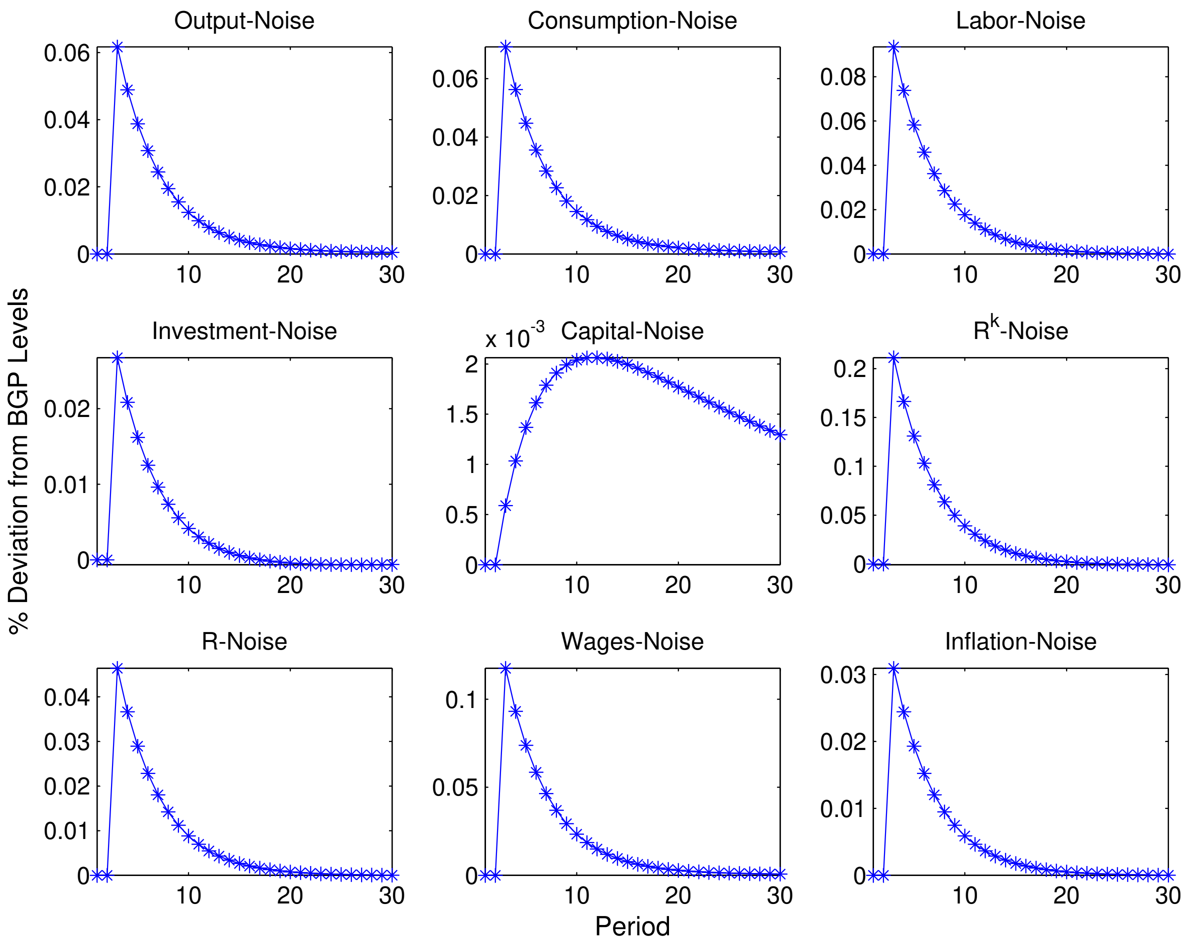

Figure 3: Impulse responses to a .01 noise shock. The x-axes are quarter periods and the y-axes are percentage deviation from previous levels.

4.6 Response to Noise Shocks

As with a permanent productivity shock, a noise shock of size $e_3 = .01$ will hit the economy in period 3, implying a 1% change in signal. This shock *only* changes $\tilde{s}_3$ to a value of .01: $\tilde{x}_t$ and $\tilde{a}_t$ will remain 0, $\forall t$ and $\tilde{s}_{3+t} = 0$, $\forall t > 0$. Using our evolution of expectations (30), we can then map what expectations will be at any future period under a noise shock:

$$\tilde{x}_{3+t|3+t} = \rho^{t-1}(1-\rho)\chi(.01), \ \forall t \geq 0 \tag{47}$$

Using the above information, I once again use the evolution of beliefs and the dynamical system to derive a series of impulse response functions in the same manner as the permanent technology shock. Figure 3 shows the resulting impulse responses.

Everything in the economy responds positively to a positive noise shock. Why? A_t has not changed, but expectations of future productivity have increased. Increased expectations of future output, coupled with nominal rigidity leading to real interest rates not adjusting quickly, lead to an increase in current output through the household's Euler equations. Again, productivity has not changed, so to fuel this output increase, more labor and more capital is introduced. With increased output comes increased labor demand, increasing wages through the labor-leisure condition. The overwhelming majority of the input response is labor; capital in comparison responds only lightly. Because of this, the marginal product of capital increases, leading to an increase in the rental rate of capital. Firms able to change their price, facing higher real marginal costs (as wages and R^k have increased but A_t has not), adjust prices upwards leading to higher inflation. Once the household begins to learn that perhaps this was not a technology shock, they slowly decumulate capital.

Recall that in Section 1.4.4 I conjectured that the output response from a noise shock would be largely consumption driven. Figure 3 substantiates this claim as consumption responds with a roughly .07% increase while investment responds with only a .025% increase. One must also take into account that consumption makes a considerably larger component of output.[15] Percent-for-percent, output responds more strongly to consumption than investment. Coupling this effect and that the actual percentage change for consumption is larger, we can safely conclude that the output response is predominantly consumption driven. Conversely, when a permanent shock occurs and expectations are joined with a current productivity increase, initial responses in output is from investment. Figure 1 shows us that aggregates initially have investment responding by 1.35% and consumption by .3%. Agents do not significantly change investment when they do not face observed productivity increasing, though they are still willing to increase consumption if only expectations change. This also helps to ultimately explain why noise shocks tend to be relatively transient.

The signal problem may also affect the observed persistence. As mentioned in Lorenzoni [15], the signal extraction problem presented in this economy is relatively simple. Lorenzoni [15] is only able to generate meaningful persistence using a model that has significantly larger information frictions than this model can afford. One thing of importance is that the general mechanism of his simple model is translated to his full-fledged model of dispersed information, which also only uses labor as a factor input. I can similarly expect the same translation would occur if I was to apply his same treatment. Then, as we will soon see, the incorporation of capital may dampen the responses that Lorenzoni [15] was achieving even

[15]The ratio of investment to output in the BGP is .209.

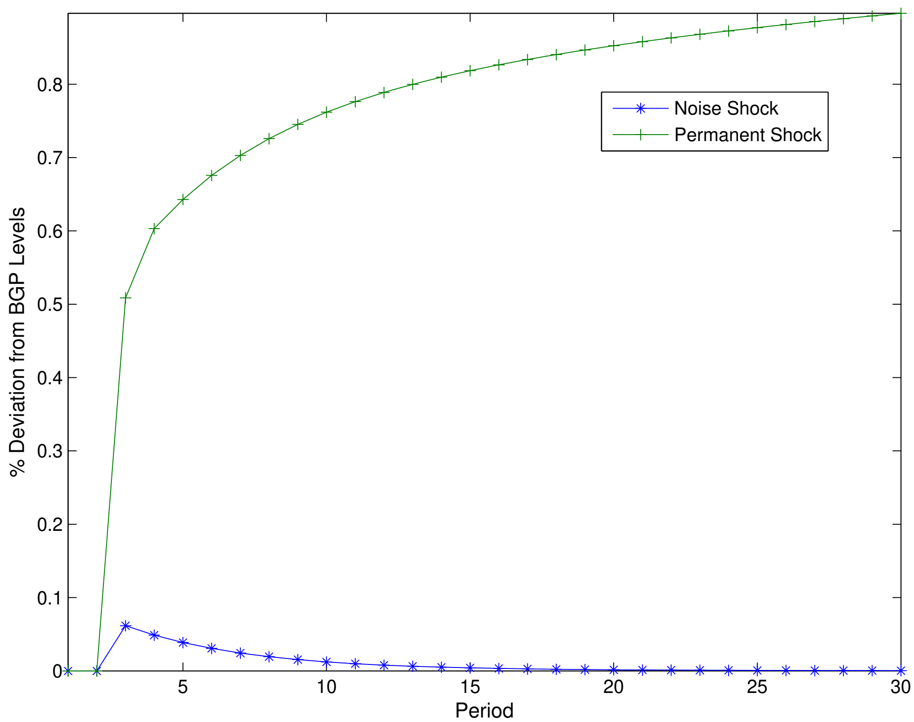

Figure 4: Comparing a noise and permanent productivity shock.

in his model of dispersed information.

4.6.1 A Discussion of Scale

Before examining what may happen in my model when we vary the significance capital, we should first ask ourselves if my model's response to noise shocks is notable in itself. A comparison of the response of a noise shock (*) versus a permanent productivity shock (+) in Figure 4 reveals that a noise shock of the same scale leads to a meek response in comparison to a true productivity shock. Upon impact of a noise shock, output responds by roughly .06%. The equivalent statistic for a permanent technology shock is roughly .5%–a response larger than eight times that of output to a noise shock. A noise shock's persistence is also small compared to a permanent technology shock, as discussed earlier.

Is this lack of a significant response facilitated or hurt by removing capital? The answer is yes and no. The inclusion of capital unequivocally decreases the initial response of the economy to noise shocks compared to the model without capital. However, because the household had misallocated an input that is not easily adjustable, the persistence of a noise shock is improved with capital and becomes even more persistent with an increase in

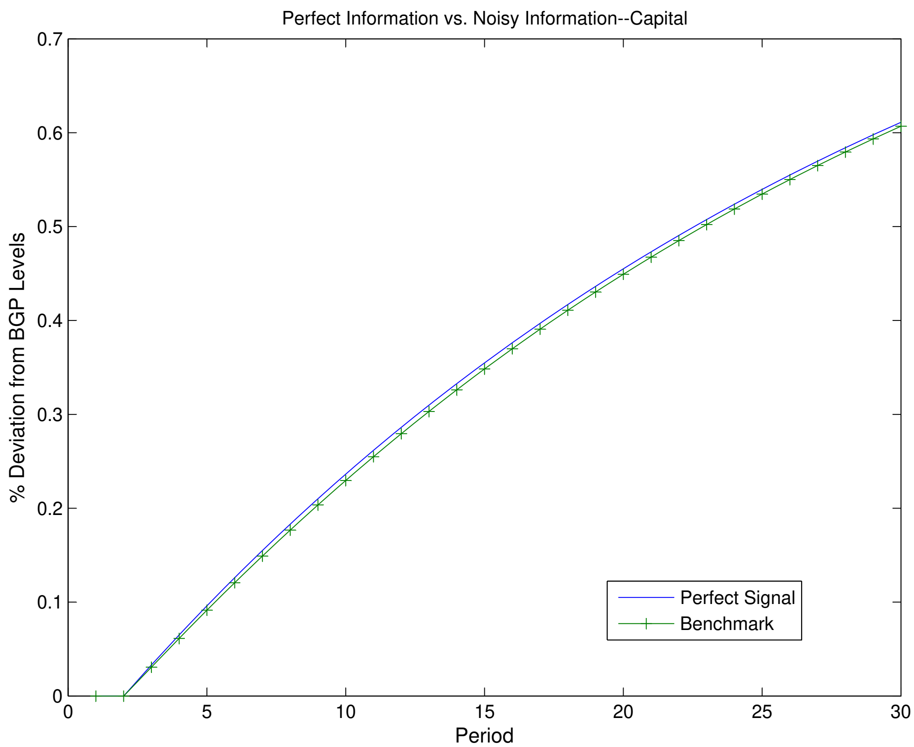

Figure 5: A permanent productivity shock's effects on capital in my benchmark and under perfect information. The y-axis is percentage deviation from each respective model's BGP.

adjustment costs.

5 Role of Capital

To what degree were the observed impulse responses due to imperfect information? Or, was it largely a consequence induced by capital itself? It turns out that the latter conjecture is the correct one. Perhaps the most telling evidence is a comparison of a positive permanent productivity shock in my benchmark (with noise) and that of its perfect information equivalent. Figure 5 compares the difference in capital accumulation between the two models, with the solid line representing perfect information and the other my benchmark. It is apparent that the differences are almost non-existent. An explanation can be seen in equation (43). The coefficient on expectations is .003. Comparing this with the coefficient on current–and observed–productivity (.03), we see that expectations play a very insignificant role in capital accumulation. Therefore, it is the typical prolonged accumulation of capital itself that ultimately resulted in the persistence observed in Figure 1, not the information separation

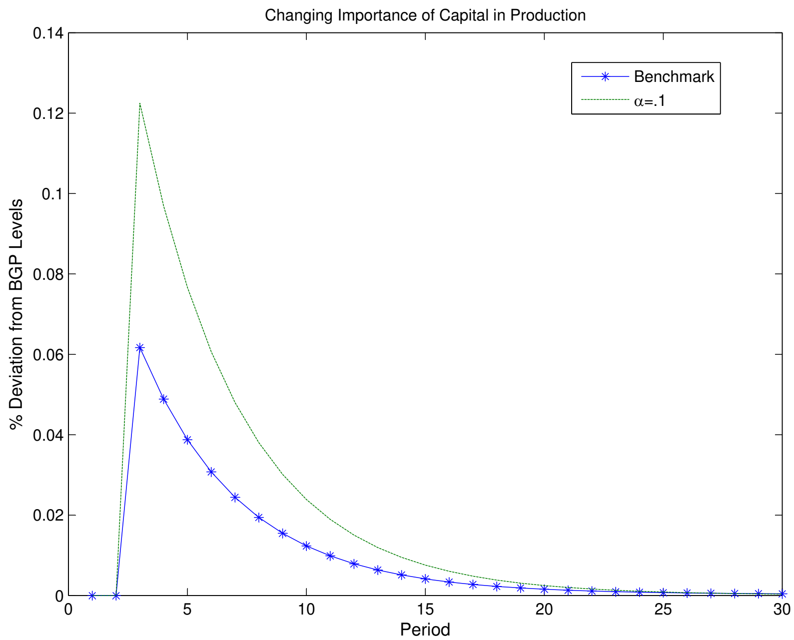

Figure 6: Output responses to a noise shock in my benchmark versus lesser importance of capital. The y-axis is percentage deviation from each respective model's BGP.

problem.

The lack of response to expectations in turn leads to negligible responses to a noise shock. When a noise shock occurs, the largest increase in capital occurs at its onset–at this point, expectations of X_t is highest and then degrades as time progresses. Capital's initial response would have been relatively small even if the household also faced an observed productivity increase, but even this is not the case. With only a change in expectations, capital gives an underwhelming response for reasons explained in the previous paragraph. With an essentially fixed factor, any significant changes in output must then be met with varying labor. However, if capital plays significant role (i.e. if α is high) then labor will face significant diminishing returns to scale. Because of this, the household responds by increasing labor but doing so in a restrained amount. If capital's role was lessened, then the degree to which we have diminishing returns in labor would be alleviated. If this logic is correct, then even with capital fixed this period, we would expect higher labor responses, leading to higher output. Evidence for this effect can be found in Figure 6, wherein I apply a 1% expectational shock and set $\alpha = .1$. In period 3, capital available for production is fixed at last period's pre-shock selected levels. Therefore, any changes in output are a direct result of changes in labor. Figure 6 shows that when $\alpha = .1$ (the solid line), output

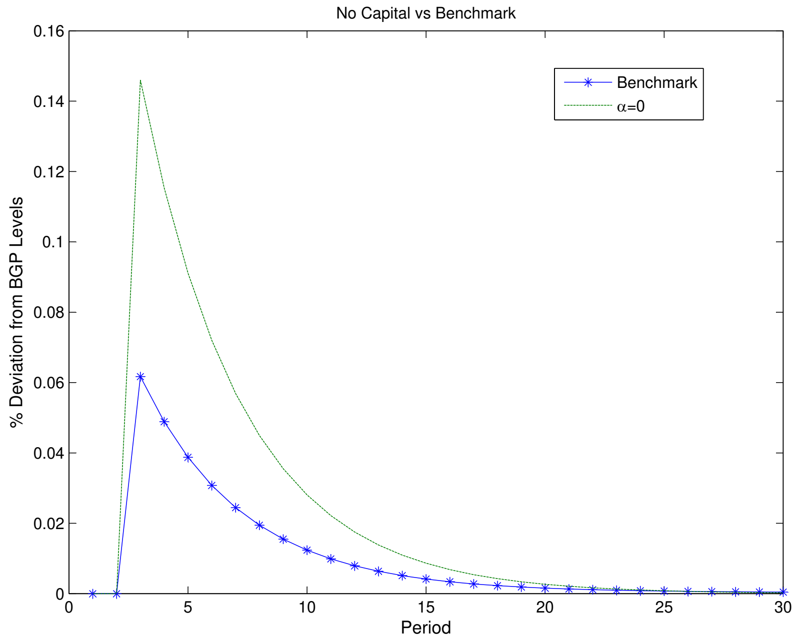

Figure 7: Comparison of responses of output to a noise shock with and without capital. The y-axis is percentage deviation from each respective model's BGP.

responds strongly to a noise shock in comparison to my benchmark (*). At this value of α, the household has a weaker effect from diminishing returns to scale and thus are more willing to provide labor in response to a noise shock. I can then conclude that the returns to scale effect from capital, coupled with usable capital this period being quasi-fixed, restrains the household's reaction to noise shocks. Thus, there would be little surprise if removing capital lead to larger scale responses from noise shocks.

5.0.2 Capital vs. No Capital

In this section, I make the assumption that $\alpha = 0$ and solve my model using the process outlined in Section 3.2, adjusted for the new assumption. I obtain the conjectured responses of inflation and output, the equivalent of (40) and (41):[16]

$$\pi_t = -.184\tilde{a}_t + .184\tilde{x}_{t|t} \tag{48}$$

$$\tilde{y}_t = .278\tilde{a}_t + .723\tilde{x}_{t|t} \tag{49}$$

Equation (49) makes it very clear that we can expect a much larger response to output

[16]As $\alpha = 0$, $\tilde{k}_t = 0$, $\forall t$, thus the term is omitted.

from expectations than in my benchmark model. The coefficient on $\tilde{x}_{t|t}$ is 2.4 times larger in (49) than (41). Applying a 1% noise shock to this no-capital model (NC) and comparing it with my benchmark in Figure 7 shows that the NC model produces a response that is 2.4 times larger than the benchmark model.

On impact of a permanent productivity shock in the NC model, output increases by .42%, implying the permanent productivity shock results in a response that is initially about four times larger than the noise shock.[17] By this measure, noise shocks seem to have a much larger possibility of being important in aggregate fluctuations. It should also be mentioned that the difference of a factor of four is considerably smaller than the eight of my benchmark!

We must then question the results of models that abstract from capital. Capital takes time to adjust. In turn, this constrains the degree to which increasing labor can result in increased output. Because of this, and that capital responds weakly to expectations, the overall economy will not respond as strongly when faced with noise shocks. Remove capital and this effect vanishes, letting agents freely respond to noise shocks as they face constant returns in labor.

When introducing capital, I also introduce convex adjustment costs. As explained in Dupor [12], the bond-capital no arbitrage condition in a New Keynesian model can lead to potential indeterminacies when using an active interest policy rule which indeed occurs in my case. This necessitates the convex adjustment costs. This may lead one to then ask: how sensitive are the above results to specifications of ϕ? The results are somewhat sensitive to its value, but the general result still holds that the NC model dominates the capital model in the scale of noise shock responses.

5.0.3 Sensitivity to ϕ

I look at my benchmark model under three ϕ values: 6, 10, and 60. I will assume a value of $\phi = 60$ for discussion.[18] Using my new assumption and applying the solution method, we get the following (40)-(42) equivalents:

$$\pi_t = -.008\tilde{k}_t - .163\tilde{a}_t + .171\tilde{x}_{t|t} \tag{50}$$

$$\tilde{y}_t = .35\tilde{k}_t + .233\tilde{a}_t + .417\tilde{x}_{t|t} \tag{51}$$

[17] A large reason why output response is initially smaller in the NC model is that labor responds more negatively upon impact.

[18] The intuition becomes very clear for the most extreme value as to how dynamics change when this parameter changes.

$$\tilde{k}_{t+1} = .988\tilde{k}_t - .996\tilde{a}_t + .008\tilde{x}_{t|t} \tag{52}$$

From (51) and (52), we can see that output and capital now respond more to expectations compared to the benchmark. The household doesn't wish to move its capital choice in large amounts and therefore is willing to respond a little bit more strongly with changes in expectations to mitigate the risk of having to make large adjustments in the capital stock. The increased capital accumulation causes an increase in output. However, comparing the coefficient on expectations in equation (51) to the same coefficient in (49), we see that output still responds considerably less to expectations than the NC model–even when capital adjustment costs are unrealistically high.

Figure 8 and Figure 9 show the different specifications and their respective output, capital, and investment responses when each model is faced with a noise shock of the same magnitude. One can see that increasing ϕ causes a stronger initial investment response, but the initial response changes very little when one moves from $\phi = 10$ (green, +) to $\phi = 60$ (red, solid). The starting point and rate of capital decumulation also differs as one moves to higher values of ϕ: at lower values, the household begins decumulating at an earlier stage and overall rate of decumulation becomes small when $\phi = 60$. This slow rate of decumulation translates to greater persistence of output to the noise shock. These two facts give evidence to my claim that the household does not wish to be caught off guard when adjustment costs are restrictive; it chooses to slowly accumulate capital until it's quite confident that this was merely a noise shock. At this point, decumulation is also quite costly. Capital then takes a prolonged amount of time to reach its proper levels.

Even in the most extreme example of $\phi = 60$, we see that the response of a noise shock in the NC model is still higher. Also, though more persistent, the level at which the noise shock persists is still negligible. The discrepancy between the NC and capital model becomes increasingly more large as the convex adjustment cost becomes less inhibitive. One can safely conclude that the conjecture of the paper still holds: capital inhibits the response of the economy to noise shocks.

6 Possible Extensions

The form of adjustment costs may affect results. For instance, a common form of adjustment cost is $\frac{\phi}{2}\frac{I_t^2}{K_t}$. If we were to compare it to my specification of incurring a cost if the capital stock changes, we may expect that this leads to a greater initial response but less persistence. For the same value of ϕ, agents must incur a larger cost for the same amount of investment

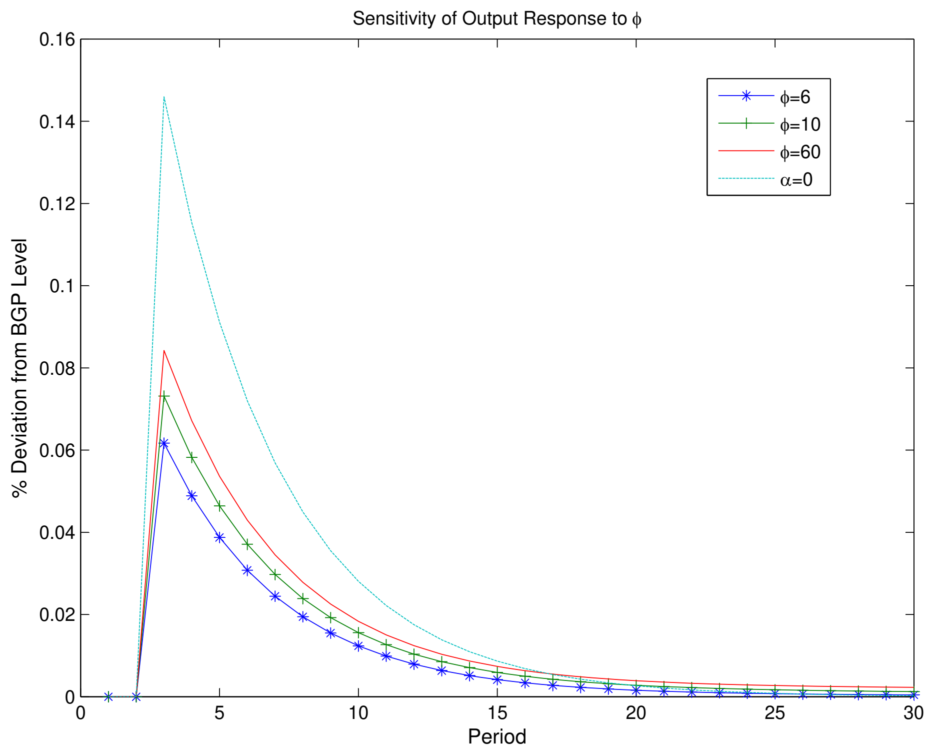

Figure 8: Output response of different specifications to a 1% noise shock

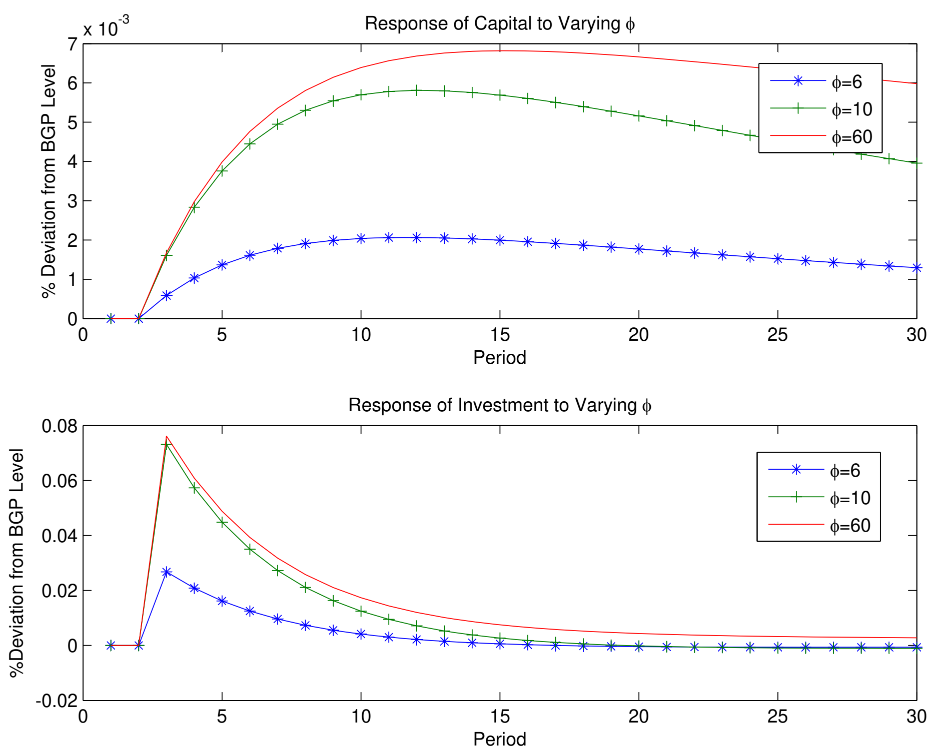

Figure 9: Capital and investment responses to a noise shock of the capital model under different values of ϕ.

in the alternative form. This would likely act like an increase of ϕ in my form and lead to a greater investment response. But recall that even at exceptionally restrictive costs, noise shocks still did not respond to the same extent as they would without capital. On the other hand, agents under the alternative form can choose to let the stock depreciate without incurring any cost. In my form, an agent wishing to decumulate capital has to incur a convex costs, perhaps causing them to decumulate more slowly and increasing the persistence of a noise shock.

Another question is the role of habit. It's likely that habit would lead to a more dampened response to a noise shock. Recall that noise shocks are largely consumption driven. If we were to mitigate the consumption response, ceteris paribus, we would likely see less of an overall output response in the economy from a noise shock.

A last thought is to apply noise shock analysis to a menu cost model. A likely candidate for menu costs, that affords tractability, would be the continuous distribution of fixed adjustment costs proposed in Dotsey et al. [11]. State-dependent pricing gives a more realistic setting of analysis, and it is the author's opinion that exploration would lead to interesting insights into firm behavior under a comparable information framework.

7 Conclusion

Capital seems to play an important role in how agents respond in an imperfect information economy. From the perspective of permanent shocks, because capital accumulation is gradual, this results in prolonged responses to permanent productivity shocks. Alternatively, when agents do not see any improvement in current technology but only get a positive signal, their response is largely consumption driven with very limited investment, causing noise shocks to lack persistence. To make a significant step towards capital accumulation, agents need a stronger signal in the form of current productivity.

Abstracting from capital gives a more extreme picture; agents are more willing to quickly adjust an input whose returns are realized today, especially when they receive constant returns in that input. Labor-only models then may show higher output volatility resulting from noise shocks due to lack of accounting for intertemporal input decisions. On the other hand, incorporating capital provides a more strenuous test to past models. If one happens to find significant responses using capital and a justifiably more complicated environment/signal extraction problem, then this would be strong supporting evidence that noise shocks are relevant.

References

[1] **Angeletos, George-Marios, and Jennifer La'O,** 2009. "Incomplete Information, Higher-Order Beliefs and Price Inertia." *Journal of Monetary Economics*, 56: S19-37.

[2] **Angeletos, George-Marios, and Jennifer La'O,** 2009. "Noisy Business Cycles" *NBER Macroeconomics Annual 2009*, edited by D. Acemoglu, K. Rogoff, and M. Woodford, 319-378.

[3] **Angeletos, George-Marios, and Alessandro Pavan,** 2007. "Efficient Use of Information and Social Value of Information." *Econometrica*, 75(4): 1103-1142.

[4] **Barsky, Robert B., and Eric R. Sims,** 2012. "Information, Animal Spirits, and the Meaning of Innovations in Consumer Confidence." *American Economic Review*, 102(4): 1343-1377.

[5] **Beaudry, Paul and Frank Portier,** 2004. "Exploring Pigou's Theory of Cycles." *Journal of Monetary Economics*, 51(6): 1183-1216.

[6] **Beaudry, Paul and Frank Portier,** 2006. "Stock Prices, News and Economic Fluctuations." *American Economic Review*, 96(4): 1293-1307.

[7] **Blanchard, Olivier J.,** 1993. "Consumption and the Recession of 1990-1991" *American Economic Review, Papers and Proeceedings*, 83(2): 270-275.

[8] **Blanchard, O., L'Huillier, J., and Guido Lorenzoni,** 2011. 'News, Noise, and Fluctuations: An Empirical Exploration." Unpublished manuscript, MIT University.

[9] **Calvo, Guilliermo A.,** 1983. "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economics*, 12(3): 383-398.

[10] **Christiano, Lawrence J.** 2002. "Solving dynamic-equilibrium models by a method of undetermined coefficients." *Computational Economics*, 20: 21-55.

[11] **Dotsey, M., King, R., and Alexander L. Wolman,** 1999. "State-Dependent Pricing and the General Equilibrium Dynamics of Money and Output." *The Quarterly Journal of Economics*, 114(2): 655-690.

[12] **Dupor, Bill.** 2001. "Investment and Interest Rate Policy." *Journal of Economic Theory*, 98: 85-113.

[13] **Faust, J., Rogers J., and Jonathan H. Wright.** 2005. "News and Noise in G-7 GDP Announcements." *Journal of Money, Credit, and Banking*, 37(3): 403-419.

[14] **Khan, Aubhik and Julia K. Thomas** 2007. "Inventories and the Business Cycle: An Equilibrium Analysis of (S,s) Policies." *American Economic Review*, 97(4): 1165-1188.

[15] **Lorenzoni, Guido.** 2009. "A Theory of Demand Shocks." *American Economic Review*, 99(5): 2050-2084.

[16] **Lucas, Robert E. Jr.** 1972. "Expectations and the Neutrality of Money." *Journal of Economic Theory*, 4(2): 103-124.

[17] **Mankiw, N. Gregory, and Ricardo Reis,** 2002. "Sticky Information Versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve." *Quarterly Journal of Economics*, 117: 1295-1328.

[18] **Maćkowiak, Bartosz, and Mirko Wiederholt.** 2009. "Optimal Sticky Prices under Rational Inattention." *American Economic Review*, 99(3): 760-803.

[19] **Morris, Stephen and Hyun Song Shin,** 2002. "The Social Value of Public Information." *American Economic Review*, 92: 1521-1534.

[20] **Phelps, E.S., Archibald, G.C., and Armen A. Alchian.** 1969. "Microeconomic Foundations of Employment and Inflation Theory." New York: Norton.

[21] **Sims, Christopher A.** 2003. "Implications of Rational Inattention." *Journal of Monetary Economics*, 50(3): 665-690.