Oil Price Shocks, Firm Entry and Exit in a Heterogeneous Firm Model

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Abstract

Oil price shocks are considered to be one of the important factors behind U.S. recessions, yet little is known about the transmission channels of oil price shocks. What complicates the matter further is the small share of oil in production. To address the issue the literature has incorporated amplifying channels such as endogenous depreciation or variable markups. This paper investigates the hitherto unexplored area of the effect of oil price shocks on firm dynamics. In particular, we seek to understand the role oil price shocks play in the entry, exit decision of firms. Using data on U.S. firm births and business failures we find that oil price shocks have a significant negative effect on firm entry and a positive effect on firm exit. This suggests that the extensive margin- the number of existing firms is an important mode of transmission for oil price shocks. We then proceed to build a DSGE model with heterogeneous firms which replicates this behavior of firm entry and exit and show that inclusion of firm entry and exit amplifies the effect of oil price shocks. Further, the DSGE model is able to explain selection patterns over the business cycle as it is the bigger and more productive firms which survive after an oil price shock..

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1 Introduction

There is a long tradition of associating oil price shocks to U.S. recessions as documented by Hamilton (1983, 1996, 2008), Burbidge and Harrison (1984), Gisser and Goodwin (1986). Oil price shocks are also thought to be an important driving force for terms of trade fluctuations (Backus and Crucini, 2000). Other studies such as Balke, Brown and Yucel (2002), Jones et al. (2004) and Kilian (2008) have focused on whether oil prices have an asymmetric effects on the economy. Given the small share of energy in GDP, standard real business cycle (henceforth RBC) models with energy as an added factor of production do not attribute an important role to oil price shocks (Kim and Lougani 1992; Rotemberg and Woodford 1996). This has led to incorporation of other channels which magnify the effects of oil price shocks. Two of the most significant contributions in this stream of literature are by Rotemberg and Woodford (1996) and Finn (2000). Rotemberg and Woodford emphasize that the assumption of perfect competition must be rejected to explain the contractionary effects of energy price shocks. In their specification, models with imperfect competition and implicit collusion are much more successful in producing contractionary effects on output in line with their empirical estimates (a 10 percent increase in energy prices causes a 2.5 percent reduction in output versus a 0.5 percent decline in a perfectly competitive model). Finn (2000) follows an alternative modeling approach where energy is not directly used in production but is required for capital utilization. She demonstrates that perfect competition along with endogenous depreciation can lead to similar drops in output. In both these approaches, channels such as variable mark-ups or capital utilization amplify the effects of energy price shocks.

This paper proposes that the extensive margin or the number of producing firms is an important channel for propagation of oil price shocks. To study this channel, we analyze the effect of oil price increases in models with endogenous determination of the number of producers. This is important as the standard approach is to treat the number of producers as constant; hence all adjustment must happen through the intensive margin or firm level production. However, as mentioned before the share of energy in U.S. GDP is small, therefore standard real business cycle models that include only the intensive margin cannot explain the sizeable effects of energy price shocks observed in empirical studies.

Our analysis shows that inclusion of the extensive margin can be an important channel for transmission of energy price shocks and amplify the effects of energy price shocks. The number of producing firms varies with respect to exogenous shocks, due to the entry and exit decisions of firms. An increase in energy prices lowers profit expectations and may deter firm entry or cause higher exit of firms. Both these effects would lower the number of producing firms when energy prices increase resulting in a bigger drop in output operating through both the extensive and intensive margins. Since the stock of firms can be thought of as a representation of the capital stock in an economy, the model is close to Finn's specification in spirit. In her model, energy affects capital accumulation through endogenous depreciation which is similar to the effect on the exit rate in our model. Note that our amplification mechanism does not depend on variable markups as the mark-up is constant in our baseline model. Moreover, both the approaches of Rotemberg and Woodford (1996) and Finn (2000) rely on a nonstandard definition of oil price shock which makes comparison with other models difficult. Our model overcomes this shortcoming by assuming a standard AR (1)[2] process for the oil price shock.

The paper makes both theoretical and empirical contributions in analyzing the effect of oil price shocks on the extensive margin of production. On the theoretical side, this is the first attempt to model oil price shocks in heterogeneous firm models with endogenous firm entry and exit.[3] Following Melitz (2003), firms differ in their

[2]A recent stream in the energy literature led by Kilian (1999) emphasizes that the economic effects of oil price increases differ depending on whether the increase is due to increase in demand for oil or due to lower supply. Indeed, oil price increases caused by high demand for oil do not seem to have significant effects on the economy (Baumeister and Hamilton, 2016). The analysis in this paper assumes that oil prices are exogenously determined and are due to supply disruptions. In that sense our analysis is more applicable to the recessions observed in the 70s. In recent years, the link between oil prices and the U.S. economy has become weaker, partly because these price increases have been due to strong demand for commodities fueled by a flourishing world economy and partly due lower dependence on oil. We think, the effects of higher oil prices as seen in this paper may still be at work except a booming economy (leading to higher product demand for firms) will counter-act the effects of higher input prices. A detailed discussion of this literature is beyond the scope of this paper.

[3]For an analysis of oil price shocks in models of only endogenous entry, refer to Patra (2014).

productivity. Oil price shocks lower expected profits and cause the firms with poor productivity to exit the market. The exit rate depends on the productivity cut-off which is a forward looking variable depending on future costs (both marginal and fixed) and future aggregate demand. Note that oil price shocks cause a decline in entry, as well, due to lower expected future profit. Both these effects lead to a bigger drop in output compared to standard models. Also, since households finance investment in the form of firm entry, the model highlights the demand channels of propagation of oil price shocks which is often overlooked in theoretical models of energy as they typically focus on supply side effects. The model also predicts an increase in energy prices would lead to a decline in real wages, labor input, investment, consumption and return on investment. All of these results are consistent with theoretical and empirical findings in the literature. In particular, the model provides an alternative way of linking firm value (stock prices) and energy prices and produces results in line with the findings of Wei (2003). In her general equilibrium model, a 10 percent rise in oil prices lead to a 0.25 percent drop in firm value while our baseline model predicts a drop of around 0.75 percent. Our model is also successful in generating a larger drop in output (a 0.5 percent decline in output in Wei's model vs. 1.2 percent in our model, while the impact on real wages and consumption is similar). The model also brings out another dimension of energy price shocks: the issue of selection. Since oil price shocks are exogenous cost shocks to firms, such shocks cause the exit of the least productive firms and raise average productivity of the surviving firms. This is an effect which cannot be modeled in symmetric firm models. Depending on the interaction between entry and exit in these models, oil price shocks can raise firm level productivity. While in traditional models, oil prices imply a drop in aggregate and firm level productivity (there is no distinction between the two in standard representative firm models) our model suggests oil prices lower aggregate productivity through its effect on the mass of firms which dominates the increase in firm level productivity.

On the empirical side, the paper is one of the first to examine the relationship between oil price shocks and firm dynamics at an aggregate level. We document that oil price shocks have a significant negative effect on firm entry. Firm exits also increase when oil prices rise. Both firm entry and exit are more responsive to oil price shocks compared to GDP. In this respect, our work relates to Davis and Haltiwanger (2001) who study the effect of oil price shocks on job creation and job destruction and employment dynamics for manufacturing jobs from 1972-1988. They find oil price shocks to be an important factor in job reallocation and both sectoral job creation and job destruction rise in response to an oil price shock. While oil price shocks may trigger considerable "allocative effects" at the sectoral level, our work suggests that for firm creation and destruction aggregate channels dominate. Another contrasting result is that while they find job destruction to be more sensitive to oil price shocks than job creation, our results are stronger for firm entry compared to exit.

It is also noteworthy that our results underestimate the effects oil price shocks on the extensive margin. This is because our measure of entry only includes new firm incorporations or net business formation. Similarly exit also is measured at the firm level in terms of Industrial failures or Establishment deaths. However these measures do not capture the introduction of new product lines or closing of existing product lines within a particular firm which is captured in the theoretical model. This is difficult to estimate in empirical settings as we lack aggregate data on product development within firms.

1.1 Related Literature

This paper contributes to several different strands of literature. Firstly, our model adds to the theoretical literature of modeling oil prices such as Rotemberg and Woodford (1996) and Finn (2000) by providing another channel of transmission through which oil price shocks affect the economy. Additionally we are able to generate amplification without relying on the standard magnifying channels such as variable mark ups or endogenous depreciation of capital. Alternative approaches to modeling the energy sector build on Atkeson and Kehoe (1999) and Wei (2003). Atkeson and Kehoe use a putty-clay mechanism of capital formation and study energy substitutability in the short and long run. Wei (2003) uses a putty-clay model with variable capital utilization to analyze the effect of oil price shocks on the stock market. These models are useful in generating asymmetric effects of shocks. However these models are not successful on generating an amplification effect on output, in general they predict a lower impact on output compared to standard models. Another strand of the energy literature focuses on the sectoral impacts of oil price shocks. Davis and Haltiwanger (2001) show that the 1973-74 oil price shock had considerable effect on job creation and job reallocation effects in the U.S. manufacturing sector. Other work by Keane and Prasad demonstrates that while oil price shocks lowers wages for all types of workers, the relative wages of skilled workers go up. Lee and Ni (2002) also study the effect of oil price shocks at a sectoral level; they show that oil price shocks act as supply shocks for the energy intensive sectors while for other sectors they primarily affect demand. While our model is an aggregate model it does highlight reallocation of resources through the entry and exit decision of firms. Oil price shocks cause reallocations from the entry sector which contracts to smooth consumption. Additionally within the production sector, endogenous exit of less productive firms implies allocation of resources to more productive firms. Our model is consistent with findings in Lee and Ni (2002) as well. Since for the aggregate economy energy expenditures are a small fraction of GDP, we would expect the demand channels of transmission to play an important role. This is successfully captured in our model thorough the entry and exit decisions of firms. As households perceive a drop in expected profits due to oil price shocks, they lower investment in the creation of new firms. Moreover existing firms also face higher costs of production and lower product demand. This increases firm exit in response to an oil price shock. Both these effects lead to a big impact on the extensive margin which amplifies the effect of oil price shocks in our model. The standard supply side models which capture only effects on the intensive margin can predict only half the impact on output that we observe in our model.

Secondly our paper contributes to a growing body of literature that emphasizes the role of firm entry and exit as an important propagation and amplification mechanism for business cycle fluctuations. This includes work of Bilbiie, Ghironi and Melitz (2012) who study the propagation of technology shocks with endogenous firm entry. Bergin and Corsetti (2008) and Bilbiie, Ghironi and Melitz (2007) focus on the effects of monetary shocks on the extensive margin. Subsequent work by Lewis (2009) compares VAR based impulse responses to those of a calibrated endogenous entry model for shocks to productivity, aggregate demand, monetary policy and entry costs. However in all these models, firms are homogeneous and the exit decision is exogenous. To introduce heterogeneity many authors have followed the approach of Hopenhayn and Rogerson (1993) who build a model with heterogeneous firms under perfect competition. Lee and Mukoyama (2012), Clementi and Palazzo (2014), Clementi, Khan, Palazzo and Thomas (2014) are some of papers which build on the Hopenhayn and Rogerson framework. In all these models, the assumption of perfect competition implies that there is no role of firm profits. This paper uses a Melitz (2003) style model to incorporate firm heterogeneity under imperfect competition to endogenize both the entry and exit decision of firms in a DSGE framework. While the Melitz (2003) model is static in nature, our model is a dynamic model with focus on business cycles[4] . In this respect, our model is related to Bilbiie, Ghironi and Melitz (2012) but differs in many aspects. Firstly we study the propagation of energy price shocks, secondly we consider heterogeneous firms and endogenize the exit rate. In their model, all firms are homogenous and the exit rate is exogenously given.

Finally our model also emphasizes the selection effects of energy price shocks. Oil price shocks in our model cause the exit of the least productive firms and raise average productivity of the surviving firms. This is an effect which cannot be modeled in symmetric firm models. Additionally, models with endogenous exit help us generate more amplification working through the extensive margin. As can be seen in comparative analysis of endogenous and exogenous exit models, symmetric firm exogenous exit models are not successful in capturing the negative effects of oil price shocks on entry or exit. The closest papers in this stream of literature are Casares and Poutineau (2014), Hamano and Zanetti (2014) and Totzek (2009). However none of these papers consider oil price shocks.

[4] Note this is not the first attempt at introducing firm heterogeneity in a dynamic setting. Melitz, and Ghironi (2005) and may other subsequent papers have used this approach. However most of this literature focuses on endogenous entry and exit into domestic versus the export market while our paper considers entry and exit of all producing firms.

Our work also closely engages with the literature on firm creation and destruction and the cleansing effects of recessions. This includes the work of Caballero and Hammour (1994) who develop a business cycle model which specifies the conditions under which recessions can be cleansing or productivity enhancing[5]. Whether recessions are cleansing or sullying in these set ups depends on the effect on creation versus destruction, if a drop in aggregate demand causes a big drop in creation, the less productive firms may be insulated and recessions may not be productivity enhancing. We are the first to demonstrate similar effects in our model for oil price shocks. In the baseline model we generate both lower entry and higher exit in response to oil price shocks. However the drop in entry is not high enough for the insulation effect to dominate and firm level productivity increases. In the model with sticky wages, oil price shocks cause a much bigger drop in entry and in that case firm level productivity falls and exit actually declines in response to an oil price shock. Lee and Mukoyama (2008) also contend that for U.S. maufacturing firms entry is more responsive to shocks. However the focus of their work is to examine the differences in entering firms in booms and recessions (selection in entry) while our model emphasizes selection in producing firms. Kehrig (2011) also develops a model based on Melitz and Ghironi (2005) which analyses the cyclical properties of the productivity dispersion between durable and non-durable sectors. More recently, Osotimehin and Pappada (2015) study the productivity enhancing reallocation effects of recessions under financial frictions. Given the absence of financial frictions in this paper, we abstain from discussing this literature in detail here.

The rest of the paper is structured as follows. In section 2, we briefly discuss the empirical evidence on the response of firm entry and exit to oil price shocks. Section 3 introduces the benchmark model. Section 4 presents sensitivity analysis with respect to key model parameters and the results from the model without entry. In section 5, we build a version of the model with sticky wages and sticky prices. Section 6 compares the models with endogenous entry and exit to the models with only endogenous entry. Section 7 concludes.

[5] Other similar models include Mortensen and Pissarides (1994), Campbell (1998) and Lentz and Mortensen (2008).

2 Firm Entry, Exit and Oil Prices Empirics

Let us first consider some facts which link oil price shocks to the onset of U.S. recessions. In Figure 1.1 we plot the movements of oil prices along with the periods of U.S. recessions from 1964 to 2013. It can be seen that except for one, all U.S. recessions have been preceded by a substantial increase in the price of oil. Hamilton (1996, 2008), Kilian (2014), Engemann et al. (2011) present further evidence in support of this hypothesis.

We propose in this paper, a role for oil price shocks in the entry and exit decision of firms which amplify the effects of oil price shocks. We expect that oil price shocks would lead to a decline in firm entry and increase in firm exit. This is because rising oil prices would lower future profit expectations through both higher production costs and lower product demand. The high comovement of entry with respect to GDP has already been noted in many studies, while the evidence on exit is mixed. Studies such as Devereux et al. (1996) report exit to be strongly counter-cyclical while recent studies such as Lee and Mukoyama (2015) find similar annual exit rates during booms and recessions. However, none of the studies above consider oil price shocks. For our analysis, we use two different measures of entry, New Incorporations and Net Business formation. The data runs from 1959:II-2013:IV for New Incorporations[6] and from 1954: III-1994: IV for Net Business Formation. The correlations[7] of entry with respect to GDP are 0.73 for Net Business Formation and 0.56 for New Incorporations. We use Industrial and Commercial Failures[8] (1954: III-1981: IV) and Establishment deaths[9] (1992: III-2013: IV) as measures of exit. The correlations

[6]The entry series is constructed from New Business Incorporations from Economagic (1959: II-1993: II) and from Private Sector Births from Bureau of Labor Statistics (1993: III-2013: IV). The Net Business formation data is from Survey of Current Business. The source of data and transformations are given in Table 1. The monthly data series was converted to quarterly series by aggregating over three months for New Incorporations while for the Net Business formation index three month average is used. The federal funds data (1954 onwards) is obtained from the St. Louis FRED data base.

[7]All the series are logged and HP filtered. The reported correlations are the correlations between the deviations from trend for the two series.

[8]The Business and Commercial failure data is monthly, sourced from Survey of Current Business. The data is converted to quarterly by summing over three months.

[9]Source of this data is Bureau of Labor Statistics.

of exit with respect to GDP are -0.6 and 0.07 in the two samples[10]. Thus, with the exception of the later sample, our evidence supports countercyclical exit. In Figure 2, we present the cross-correlations of entry and exit with respect to real oil prices at various lags. It can be seen that for both the measures of firm entry the cross-correlations are negative and significant. This suggests that oil price increases deter entry in the future periods as fewer firms enter the market in anticipation of lower profits. The cross-correlations for exit are positive and significant for both measures of exit suggesting that oil price shocks may result in more firm exits in the future.

To formally study the effects of oil price shocks on firm entry, we estimate a VAR (3) model with real GDP, Federal funds rate, entry measured as Net Business Formation (NBF) or New Incorporations (NI), GDP deflator and the Hamilton measure of oil prices ($x_t^{\#}$)[11]. We choose a lag length of 3 following Akaike information criterion (AIC). The Hamilton variable uses quarterly data on producer price index (PPI) for crude oil prices and is calculated in the following way;

$x_t^{\#} = \max\{0, X_t - \max\{X_{t-1}, ..., X_{t-12}\}\}$, where X_t is log level of the PPI value.

We use the Hamilton indicator variable as a measure for oil price as it allows us to isolate "large" oil price increases thought to have the strongest impact on economic activity[12]. Figures 3.1 and 3.3 show the impulse responses with respect to an oil price shock identified as the Hamilton variable. One can see that a one standard deviation in oil price causes a decline in firm entry approximately 4 quarters later. The response of entry is statistically significant for both the measures of entry, the maximum impact is around 0.6 percent for both the measures of entry. The response of GDP is also similar across the VAR specifications with a drop of 0.2 percent and 0.17 percent after 4 quarters for the longer and shorter sample respectively. Both

[10] The first correlation coefficient is statistically significant while the second is not.

[11] Identification is done by Choleski decomposition method, with oil as the first variable. We also run a VAR with real oil prices as a measure of oil price shocks. Our results show oil price shocks have a significant effect on firm entry while the response of exit is not statistically significant. The transformations are given in Table 1.

[12] Since we have data only at the establishment level, we presume that the oil price shocks have to be substantial to cause establishments to delay entry or exit the market completely. We think entry, exit at the product level would be even more responsive to oil price shocks but aggregate data on product development is currently lacking.

the fed funds rate and GDP deflator increase following an oil price shock.

For the response of exit, we estimate a similar VAR model [13]. The lag length is set at 2 according to AIC criterion. The results show that after an oil price increase, exit rates go up by 1.7 percent, 7 quarters after the shock. The response is statistically significant in the case where exit is measured as Industrial and Commercial failures. When we use establishment death as exit, rates go up by 1 percent 3 quarters after the shock. The response is marginally significant in this case.

A number of conclusions can be drawn from the VAR impulse responses. Firstly, energy prices impact the entry and exit decisions of firms. In fact, firm entry and exit are much more responsive to energy price shocks than GDP. Secondly, there is a delay in the response of both entry and exit which suggests lags in setting up or closing establishments. It is important to note that the VAR models probably understate the response of the extensive margin. The reason for this is that the measure of entry only includes new firm incorporations or net business formation. Similarly exit also is measured at the firm level in terms of Industrial failures or Establishment deaths. However these measures do not capture the introduction of new product lines or closing of existing product lines within a particular firm which the theoretical model described below captures. This is difficult to capture in empirical settings as we lack aggregate data on product development within firms. The main implication from this exercise is that firm entry and exit respond to energy prices shocks and should therefore be included as a transmission channel in theoretical models.

3 Benchmark Model

In this section we build a framework where energy prices impact the extensive margin through firm entry and exit. Since the entry and exit decision depends on expected

[13] Instead of running a VAR with measures of both entry and exit, we study entry and exit separately. This is done due to data availability. We only report the impulse responses of Exit in the paper for this VAR. The impulse responses for the other variables in the VAR are qualitatively the same as in the Entry VAR. For the Exit VAR with Industrial and Commercial Failures as exit we calculate growth rates by taking period t and $t-4$.This is done to correct for seasonal variation in the data.

profits, it is crucial that firm profits respond to oil price shocks in our model setup. To achieve this goal, we use a lag to build and sunk cost of entry as in Bilbiie, Ghironi and Melitz (2012) to generate procyclical profits. There is no capital in the model, hence all investment is geared towards the extensive margin. Firms are heterogeneous with respect to firm specific productivity. There is a fixed cost of production and firms may optimally decide to exit the market if the expected stream of future revenue is less than the stream of fixed costs.

3.1 Firms

There is a continuum of firms each specializing in the production of a specific variety of the intermediate good in each period[14]. There are two factors used in production of each variety, labor and energy. Production entails both fixed and marginal costs. Firms differ in their productivity level z but share the same fixed cost $f > 0$. A firm with higher productivity can produce at a lower marginal cost. Since we abstain from modeling multi-product firms, each firm with a particular productivity level produces a particular variety of the intermediate good. Therefore there is a one to one correspondence between the productivity level, the firm and the intermediate good it produces. This allows us to use z as an index for the intermediate goods as well. The intermediate goods are aggregated to final goods using a CES aggregator to be defined in the aggregation section below.

Output of each variety is given as

$$y_t^c(z) = z l_t^c(z)^\alpha m_t^c(z)^{1-\alpha} - zf,$$

where z is firm specific productivity, $l_t^c(z)$ and $m_t(z)$ stand for labor and energy used for production of variety z. The cost function can be written as $C(y_t^c(z)) = \left(\frac{y_t^c(z)}{z} + f\right) b w_t^\alpha p_{mt}^{1-\alpha}$, where $b = \alpha^{-\alpha}(1-\alpha)^{\alpha-1}$, w_t is the real wage rate and p_{mt} is the real price of energy. The marginal cost of production is given as $MC = \frac{b w_t^\alpha p_{mt}^{1-\alpha}}{z} =$

[14] Since there is a one-to-one correspondence between firms and products varieties, the model can also be interpreted in terms of firm entry or creation of new products. The second interpretation allows for contribution of product creation and destruction over the business cycle.

$\lambda_t^p(z)$. Demand for each variety is $y_t^c(z) = \left(\frac{p_t(z)}{P_t}\right)^{-\theta} Y_t^c$, where $p_t(z)$ is the price of each variety, P_t is the aggregate price index of the consumption good and Y_t^c is the final consumption good.

The firm's problem can be formulated as a two stage problem where the first step involves cost minimization and the second step is the price setting problem. In the first stage the firms cost minimization problem can be written as

$$min \quad w_t l_t^c(z) + p_{mt} m_t(z)$$

$$s.t.$$

$$y_t^c(z) = z l_t^c(z)^{\alpha} m_t^c(z)^{1-\alpha} - zf$$

which gives us the first order conditions given below:

$$w_t = \frac{\alpha \lambda_t^p(z) \left(y_t^c(z) + zf\right)}{l_t^c(z)}, \tag{1}$$

$$p_{mt} = \frac{(1-\alpha)\, \lambda_t^p(z) \left(y_t^c(z) + zf\right)}{m_t(z)} \tag{2}$$

In the second stage the firm acts as a price setter and solves the following problem

$$max \ \rho_t(z) y_t^c(z) - \left(\frac{y_t^c(z)}{z} + f\right) b w_t^{\alpha} p_{mt}^{1-\alpha}$$

$$s.t.$$

$$y_t^c(z) = \left(\frac{p_t(z)}{P_t}\right)^{-\theta} Y_t^c$$

The first order condition for this problem is

$$\rho_t(z) = \mu \frac{b w_t^{\alpha} p_{mt}^{1-\alpha}}{z}, \tag{3}$$

where $\rho_t(z) = \frac{p_t(z)}{P_t}$ is the relative price of the intermediate good with respect to the aggregate consumption good. Each firm set prices as a constant markup (μ) over marginal cost, where

$$\mu = \frac{\theta}{\theta - 1}. \tag{4}$$

Real operating profits (not including entry costs) can be expressed as

$$d_t(z) = \rho_t(z) y_t^c(z)[1 - 1/\mu] - f b w_t^{\alpha} p_{mt}^{1-\alpha}. \tag{5}$$

Real revenue for each firm is

$$r_t(z) = [\rho_t(z)]^{1-\theta} Y_t^c, \tag{6}$$

which implies that the ratio of the revenue for two firms will depend only on their respective productivities.

$$\frac{r_t(z_1)}{r_t(z_2)} = \left(\frac{z_1}{z_2}\right)^{\theta-1}. \tag{7}$$

3.2 Aggregation

For solving the model, we use the aggregation technique as described in Melitz (2003). We accordingly define $\widetilde{z}$, a weighted average of the firm productivity levels as given below

$$\widetilde{z} = \left[\int_{z_{\min}}^{\infty} z^{\theta-1} g(z) dz\right]^{\frac{1}{\theta-1}} = K z_{\min}. \tag{8}$$

Under a Pareto distribution the average productivity can be written as; $\widetilde{z} = K z_{\min}$ where $K = \left(\frac{\kappa}{\kappa-(\theta-1)}\right)^{\frac{1}{\theta-1}}$. After defining the average productivity in this fashion, we can express aggregate variables in terms of N_t and the corresponding variables for the firm with the average productivity level. For aggregate variables it does not matter whether we have N_t firms with different productivities or N_t firms with the same productivity level $\widetilde{z}$. This makes solving the model much easier. The aggregate price level (P_t) , aggregate revenue (R_t), aggregate manufacturing output (Y_t^c), aggregate profits (Π_t) can be expressed in terms of N_t and the corresponding variables for the firm with the average productivity level $(\widetilde{z})$, $p_t(\widetilde{z})$, $r_t(\widetilde{z})$, $y_t^c(\widetilde{z})$, $d_t(\widetilde{z})$ in the following way:

$$P_t = N_t^{1-\mu} p_t(\widetilde{z}), \tag{9}$$

$$Y_t^c = N_t^{\frac{\theta}{\theta-1}} y_t^c(\widetilde{z}), \tag{10}$$

$$R_t = P_t.Y_t^c = N_t r_t(\widetilde{z}), \tag{11}$$

$$\Pi_t = N_t d_t(\widetilde{z}). \tag{12}$$

Profits for the average firm or the firm with the average productivity can be written as:

$$d_t(\widetilde{z}) = [1 - 1/\mu]\frac{Y_t^c}{N_t} - fbw_t^{\alpha} pm_t^{1-\alpha}, \tag{13}$$

Rewriting the wage equation from the firms' first order conditions:

$$w_t = \alpha \left[\frac{Y_t^c - N_t d_t(\widetilde{z})}{L_t^c}\right], \tag{14}$$

Similarly the energy price equation can also be re-written in the following manner:

$$p_{mt} = (1-\alpha)\left[\frac{Y_t^c - N_t d_t(\widetilde{z})}{M_t}\right], \tag{15}$$

where L_t^c and M_t refer to the total labor and energy usage in the production sector.

3.3 Firm Entry and Exit

Entry and exit take place at the intermediate good level. In each period there is a mass N_t of producing firms in the economy and an unbounded mass of prospective entrants. Entering firms compare the returns from entry, the present discounted value of expected profits to the cost of entry when making the decision to enter. We assume for simplicity that entry costs are in terms of labor only in the baseline model[15]. Namely, each firm pays a sunk entry cost $f_{e,t}$ in units of labor, the cost of entering is then $C_{e,t} = f_{e,t}w_t$.

The production technology for entry (with $N_{e,t}$ entering firms every period) can be written as $f_{e,t}N_{e,t} = L_t^e$ where L_t^e refers to the the labor used in building $N_{e,t}$ firms. The expected post entry value of the firm in period t is determined by the present discounted value of expected future stream of profits from period $t+1$ onwards : $v_t(\widetilde{z}) = E_t \sum_{s=t+1}^{\infty} Q_{t,s}d_s(\widetilde{z})$, where $Q_{t,s}$ is the stochastic discount factor determined in equilibrium by the optimal investment behavior of households. The free entry condition given below implies that entry occurs until the average firm value equals the entry cost (in real units)

$$v_t(\widetilde{z}) = C_{e,t} = f_{e,t}w_t. \tag{16}$$

A positive mass of entrants ensure that this condition holds every period.

After the entry costs are paid, the new firms draw their productivity z, from a common distribution $g(z)$. This productivity level is thereafter fixed for the entire lifetime of the firm. As is common in the literature, we take $g(z)$ to be a Pareto distribution with support over $[z_{\min}, \infty)$.The entrants entering in period t start producing in period $t+1$. This lag to build assumption implies that the stock of producing firms is fixed in the short run and responds slowly to macroeconomic shocks. It may be interpreted as time required to set up the distribution network or establish clientele base before the firms start selling. This assumption is significant and along with sunk

[15] We also consider a modification where energy along with labor is used for entry. The results are qualitatively unaffected under this alternative assumption.

cost of entry generates pro-cyclical profits and entry, which cannot be explained with frictionless entry as in Chatterjee and Cooper (1993), Devereux, Head and Lapham (1996) and Jaimovich and Floetotto (2008).

The exit decision takes place at the end of the period. Both incumbent and entering firms make a decision to exit at the end of the period if their productivity level is too low compared to the productivity threshold. The productivity threshold, z_t^* is the level of productivity when the expected value of future profits is zero. The cut-off productivity level is determined by the following equation:

$$E_t(\sum_{j=1}^{\infty} Q_{t,t+j} d_{t+j}^*) = 0 \tag{17}$$

where d_{t+j}^* is the real profit for the firm with the threshold productivity level and $Q_{t,t+j}$ is the stochastic discount factor to be defined later. For any firm with productivity value $z < z_t^*$, it is optimal to exit as it is not expected to break even. However, a firm may make negative profits in some periods and choose to stay on if future profits are expected to be high. The value of z_t^* fluctuates from period to period depending on the state of the economy.

We can formalize the law of motion for firms in the following way. In the beginning of period t, there are N_t producing firms. After production, each firm decides on whether to produce in the next period or not by comparing its productivity with the threshold productivity z_t^*. Entrants also face a similar problem and may optimally decide to exit without producing if their productivity is lower than z_t^*.

The timing of entry and production imply the number of producing firms during period $t+1$ is given by:

$$N_{t+1} = (1 - \delta_t)(N_t + N_{e,t}). \tag{18}$$

The number of producing firms can be interpreted as the stock of capital of an economy and is an endogenous state variable that behaves like physical capital in the standard RBC model. Given the assumption of Pareto distribution the exit rate, δ_t , depends on the productivity threshold z_t^* as follows

$$\delta_t = 1 - \left(\frac{z_{\min}}{z_t^*}\right)^{\kappa}, \tag{19}$$

where κ is the shape parameter and $z_{\min}$ the lower bound of the Pareto distribution.

The number of exiting incumbents denoted by N_t^X, is

$$N_t^X = \delta_t(N_t) \tag{20}$$

while the number of surviving incumbents is given as

$$N_t^A = (1 - \delta_t)(N_t).$$

3.4 Consumers Problem

The representative household maximizes expected lifetime utility,

$$E_t[\sum_{i=0}^{\infty} \beta^i U(C_{t+i}, L_{t+i})],$$

where β is the subjective discount factor, C_t refers to aggregate consumption and L_t is labor supply. The period utility function is given as $U(C_t, L_t) = \ln C_t - \frac{\chi L_t^{1+1/\varphi}}{1+1/\varphi}$ where $\chi > 0$ is the weight of disutility of labor and $\varphi > 0$ represents the Frisch elasticity of labor supply to wages and the intertemporal elasticity of substitution in labor supply. We can write aggregate consumption and price level in terms of varieties in the following way: $C_t = \left[\int\limits_{\omega \in \Omega} c_t(\omega)^{\frac{\theta-1}{\theta}} d\omega\right]^{\frac{\theta}{1-\theta}}$, where $\theta > 1$ is the elasticity of substitution between goods, $P_t = \left[\int\limits_{\omega \in \Omega} p_t(\omega)^{\frac{\theta-1}{\theta}} d\omega\right]^{\frac{\theta}{1-\theta}}$ is the consumption based price index with $p_t(\omega)$ being the nominal price of variety ω. The Demand Function for each variety is given as: $c_t(\omega) = \rho_t(\omega)^{-\theta} C_t$.

As mentioned before, each intermediate variety is produced by a particular firm with a certain productivity level. We can therefore re-write the households' optimality conditions in terms of the firm with productivity level $\widetilde{z}$ as shown in the following section.

3.4.1 Household Budget Constraint and Optimality Conditions

The household budget constraint is given as:

$$\widetilde{v}_t(N_t + N_{e,t})x_{t+1} + C_t = (\widetilde{d}_t + \widetilde{v}_t)N_t x_t + w_t L_t, \tag{21}$$

where x_t is the share in the mutual fund held by the representative household in period t. $\widetilde{v}_t, \widetilde{d}_t$ refer to value and profits for the average firm, we suppress the $\widetilde{z}$ notation for brevity. The left hand side represents household expenditure on future share holdings in a mutual fund of existing firms and entering firms and consumption. The household does not know which firms will exit so finances all entering firms. The right hand side represents income from dividends, income from selling current share holdings and labor income.

The households first order conditions are given below:

$$C_t : \qquad \frac{1}{C_t} = \lambda_t \tag{22}$$

where λ_t is the Lagrange multiplier associated with the household's budget constraint.

$$x_{t+1} : \widetilde{v}_t = \beta \frac{N_t^A}{N_t} E_t[\frac{C_t}{C_{t+1}}(\widetilde{d_{t+1}} + \widetilde{v_{t+1}})], \tag{23}$$

$$L_t : \chi \left(L_t\right)^{\frac{1}{\varphi}} = \frac{w_t}{C_t}, \tag{24}$$

Iteration of the Euler equation and elimination of speculative bubbles allow us to solve for the stochastic discount factor $Q_{t,s}$:

$$Q_{t,s} = \beta^s [\frac{C_t}{C_{t+s}}] \prod_{i=0}^{s} \left(\frac{N_{t+i}^A}{N_{t+i}} \right). \tag{25}$$

3.5 Market Clearing Conditions

3.5.1 Labor Market Equilibrium

Total labor supplied (L_t) must equal labor demand from the production and entry sector

$$L_t = L_t^c + L_t^e. \tag{26}$$

Aggregate labor demand for the production sector (L_t^c) is sum of firm level labor demand (l_t^c), $L_t^c = N_t l_t^c(\widetilde{z})$. Similarly, aggregate labor demand for entry is

$$L_t^e = N_{e,t} l_t^e(\widetilde{z}) = \frac{\alpha \widetilde{z} \lambda_t^p(\widetilde{z})(N_{e,t} f_{e,t})}{w_t}. \tag{27}$$

3.5.2 Energy Market Equilibrium

Total energy usage is sum of energy usage in production for all firms, $M_t = N_t m_t(\widetilde{z})$.

3.5.3 Balance Trade Condition

We impose a balanced trade condition every period, the consumption good is exported to pay for energy imports. In terms of aggregate variables, the balance trade condition implies

$$Y_t^c = C_t + p_{mt} M_t. \tag{28}$$

3.5.4 Aggregate Resource Constraint

Summing over all households, imposing $x_{t+1} = x_t = 1$, and adding the energy expenditure gives us the aggregate resource constraint;

$$Y_t \equiv C_t + p_{mt} M_t + \widetilde{v}_t N_{e,t} = N_t \widetilde{d}_t + w_t L_t + p_{mt} M_t. \tag{29}$$

Total expenditure on consumption and investment in new firms must equal total income from profits and labor. Note that $\widetilde{v}_t N_{e,t}$ represents investment in new firms. Investment on the intensive margin can be included by adding capital in the model.

However inclusion of capital may allow for another intertemporal reallocation channel and dampen the impact of shocks on entry.

Total consumption output Y_t^c is given as,

$$Y_t^c = \rho_t(\widetilde{z})\widetilde{z}\,(L_t^c)^{\alpha}\,(M_t^c)^{1-\alpha} - N_t\widetilde{z}f. \tag{30}$$

3.6 Derivation of the Productivity Threshold

The firm level profits can be expressed as a function of the markup (μ), aggregate consumption output (Y_t^c), the number of firms (N_t), fixed cost (f),real wages (w_t) and the price of energy (p_{mt}). Rewriting the cut-off productivity condition as, $\sum\limits_{j=1}^{\infty} Q_{t,t+j} d_{t+j}^*(z_t^*) = \sum\limits_{j=1}^{\infty} Q_{t,t+j}\left(\rho_{t+j}(z_t^*)y_{t+j}^c(z_t^*)[1-1/\mu] - fbw_{t+j}^{\alpha}p_{mt+j}^{1-\alpha}\right) = 0.$

Given the demand function for each variety, we can replace $y_{t+j}^c(z_t^*)$ in the following way

$$\sum_{j=1}^{\infty} Q_{t,t+j}\left(\rho_{t+j}(z_t^*)^{1-\theta}Y_{t+j}^c[1-1/\mu] - fbw_{t+j}^{\alpha}p_{mt+j}^{1-\alpha}\right) = 0.$$

We use the pricing condition to write the equation in terms of marginal costs,

$$\sum_{j=1}^{\infty} Q_{t,t+j}\left[\left(\mu\lambda_{t+j}^p(z_t^*)\right)^{1-\theta} Y_{t+j}^c[1-1/\mu] - fbw_{t+j}^{\alpha}p_{mt+j}^{1-\alpha}\right] = 0.$$

Note, $\lambda_{t+j}^p(z_t^*) = \lambda_{t+j}^p(\widetilde{z})\frac{\widetilde{z}}{z_t^*}$,therefore we can write the equation as

$$\sum_{j=1}^{\infty} Q_{t,t+j}\left[\left(\mu\lambda_{t+j}^p(\widetilde{z})\frac{\widetilde{z}}{z_t^*}\right)^{1-\theta} Y_t^c[1-1/\mu] - fbw_t^{\alpha}p_{mt}^{1-\alpha}\right] = 0.$$

Log-linearizing around the steady state we get the following equation governing the dynamic behavior of z_t^*;

$$\widehat{z_t^*} = \overline{\beta}\widehat{z_{t+1}^*} + (1-\overline{\beta})\widehat{\lambda_t^p(\widetilde{z})} + (1-\theta)^{-1}\widehat{Y_{t+1}^c} - (1-\theta)^{-1}\widehat{X_{t+1}}, \tag{31}$$

where $X_{t+1} = fbw_{t+1}^{\alpha} p_{mt+1}^{1-\alpha}$, $\widehat{X_{t+1}} = \alpha \widehat{w_{t+1}} + (1-\alpha)\widehat{p_{mt+1}}$ and $\overline{\beta} = \beta \left(\frac{N^A}{N}\right)$

The cut-off threshold level depends positively on the marginal costs and fixed costs ($\theta > 1$) and negatively on aggregate demand. Thus both supply and demand side factors influence the distribution of firms. Higher costs and lower demand make it harder for firms with low productivity to survive and consequently, the productivity threshold goes up.

3.6.1 Calibration

This section presents the parameter values used for calibration in the baseline model. The benchmark calibration values and interpretations are summarized in Table 2. The share of energy in value added is given as

$$\frac{p_m M}{Y - p_m M} = \frac{(1-S)(1-\alpha)}{1+\gamma-(1-S)(1-\alpha)} \tag{32}$$

where $S = (1-\frac{1}{\mu})(\frac{\theta-1}{\kappa})$ and $\gamma = \frac{1}{\theta}\frac{\delta}{r+\delta}$. We calibrate $\alpha = 0.9437$, such that the share of energy in GDP is 4 percent. This is close to the value used in Finn (2000) and Rotemberg and Woodford (1996). The steady state value for energy price, p_{mt} is taken to be 1. The fixed cost of entry parameter f_e is taken to be 1 following Bilbiie et al. Since periods are interpreted as quarters, β is set to be 0.99 which implies a 4 percent annual interest rate. The value of θ is fixed at 3.8 following Bernard et al. The parameter for disutility of labor χ, is set to be 0.924271 as in Bilbiie et al. (2012) which gives a labor supply of 1 in the steady state. The elasticity of labor supply ϕ is set to 4 which is consistent with King and Rebelo (1999). $z_{\min}$ is normalized to 1. We set $\delta = 0.29$, $\kappa = 4$ following Casares et al. (2014). The steady state fixed cost, f is determined through the Euler equation , $\widetilde{v} = \beta(1-\delta)(\widetilde{v} + \widetilde{d})$. δ refers to the exit rate $\frac{N^X}{N}$ in the steady state. From the free entry condition, $\widetilde{v} = wf_e$. In addition, the sum of profits for all periods must be zero for the cut-off productivity firm by definition. This implies that the cut-off firm must be making zero profits every period. Therefore, $d^* = 0$, or $r^* = fbw^{\alpha}p_m^{1-\alpha}$. Given that the ratio of revenues depend only on the productivity levels of the firms, we know that

$r(\widetilde{z}) = \left(\frac{\widetilde{z}}{z^*}\right)^{\theta-1} r^*$. We can use this relation, to express the average profit or profit of the firm with the average productivity level in terms of z^* and r^*. Therefore, $\widetilde{d} = d(\widetilde{z}) = \left[\left(\frac{\widetilde{z}}{z^*}\right)^{\theta-1} - 1\right] fbw_t^{\alpha} p_{mt}^{1-\alpha}$. Substituting for $\widetilde{d}$ and $\widetilde{v}$ in the Euler equation we get the following equation which gives us the value of f in the steady state.

$$f = \frac{(1-\beta(1-\delta))\, w^{1-\alpha} f_e}{b\beta(1-\delta_n)\left(\frac{\kappa-(\theta-1)}{\theta-1}\right)} \tag{33}$$

The exogenous variable p_{mt} is assumed to follow an AR (1) process in logs which is common in the literature[16]. The exogenous process for p_{mt} is given below:

$$log(p_{mt}) = \ \phi_m \log(p_{mt-1}) + \varepsilon_{m,t} \qquad \varepsilon_{m,t} \sim N(0, \sigma_{mz}^2).$$

We estimate the exogenous process for real oil prices[17] using U.S. data from 1959: II-2013: IV. The persistence of the energy price process ϕ_m and the standard deviation σ_{mz} are estimated to be 0.99 and 0.127 respectively.

3.7 Model Dynamics

We solve the model and obtain impulse responses using first order linear approximations.[18] Figure 5.1 and figure 5.2 present the impulse responses from the DSGE model with respect to an energy price shock. The horizontal axis represents number of quarters. The impulse responses are scaled to a 10 percent increase in energy prices for comparison with the other papers in the literature and presented as percentage deviations from steady state values.

The energy price shock reduces energy imports (M_t). Firm level output ($\widetilde{y}_t$) and profits ($\widetilde{d}_t$) fall on impact. As the entry sector contracts L_t^e falls on impact, households choose to reallocate labor from entry to production. However since all firms are producing less, labor demand is low in production which leads to a drop in

[16]RW (1996) and Finn (2000) use a different specification for energy price shocks which makes comparison with this model somewhat difficult.

[17]For this estimation, we fit an AR(1) model to the logged real oil price data.

[18]We use Dynare to obtain the numerical results. For the impulse response labeling we skip the tilde notation. All firm level variables refer to the average firm.

real wages. Households supply less labor due to fall in real wages. $GDP_t = C_t + \widetilde{v}_t N_{e,t}$, falls as both consumption and investment fall. The maximum fall in GDP on impact is about 1.2 percent due to a 10 percent increase in energy prices. Most of the drop in GDP is due to fall in investment in the extensive margin (around 6 percent) while response of consumption on impact is about 0.4 percent.

Because the number of firms N_t is predetermined, it is not affected by shocks on impact. Any variable which is only a function of N_t will also behave similarly and will only change over time. Relative prices $\widetilde{\rho}_t$ therefore remain constant on impact (see equation 14). Given constant markups in this model, marginal cost of production $\widetilde{\lambda}_t^p$must be constant on impact, this follows from the firms pricing equation (equation 3). As a result, a rise in energy prices is accompanied by a fall in real wages. We assume the marginal cost of entry consists only of labor so the entry cost must fall. However, as profits fall, the returns to entry ($\widetilde{re}_{t+1} = \frac{\widetilde{v_{t+1}} + \widetilde{d_{t+1}}}{\widetilde{v_t}}$) are also lower. Entry falls to equate the cost of entering to average firm value (if the cost to entering was held constant, the impact on entry would be higher as we will discuss later). As households accommodate shocks thorough lower entry, the response of consumption is not proportional to the shock on impact. The productivity cut-off z_t^* increases on impact as profits fall and firms face lower demand for their output. This causes a higher exit and firms from the lower end of the distribution fail to survive. The exit cut-off also indirectly impacts entry decisions. Firms realize that the conditions for survival are worse in future and this leads to even lower entry in this model compared to a situation where the exit cut-off remained unchanged.

Over time the lower entry and higher exit leads to fewer firms, N_t falls. As the number of varieties fall during transition, demand for each variety increases which leads to higher firm level output. Relative prices $\widetilde{\rho}_t$ falls as there are fewer varieties. This is also reflected in lower firm value. Average profits increase which offsets the decrease in $\widetilde{v}_t$ so that $\widetilde{re}_{t+1}$ increases above its steady state value over the transition period. Labor is reallocated back to the entry sector, entry increases over time. As profits increase, the exit rate also declines. Consumption response is hump -shaped and it drops further to about 0.8 percent as households cut back on consumption to finance entry. Wages drop further as even though firm level production is higher, there are fewer firms than before so aggregate labor demand is lower. As entry increases and exit declines, N_t starts increasing till the number of varieties is back to its old steady state value. Investment $(\widetilde{v}_t N_{e,t})$ keeps increasing along with consumption and GDP goes back to its old steady state value. Comparing theoretical results with the empirical responses we see that the model over estimates the impact on entry while the response of the exit rate is similar in magnitude. The theoretical model predicts a 5 percent decline in entry and a 2 percent increase in the exit rate on impact. The corresponding estimates for entry[19] are between 2-3 percent for the two measures in the VAR models (for a 10 percent increase in oil prices) after about 4 quarters. The responses of the exit rate are similar about 2-3 percent for a 10 percent increase in oil prices after 6 quarters. Thus in spite of the fairly simple structure of the model, it captures the right sign and magnitude for entry and exit. The responses of GDP are about 1-1.6 percent in the VAR models while the model predicts a 1.2 percent decline. However the model is not successful in capturing the "u" shaped responses in the data. In the model entry and exit adjust instantaneously to shocks while the empirical results suggest that there is a lag in response of entry and exit to oil price shocks.

4 Sensitivity Analysis

4.1 Model without Entry or Exit

The no entry case helps us identify the amplification solely due to inclusion of entry and exit. We assume $N_{e,t} = 0, N_t = 1, \delta = 0, \mu = 1.35$. Since there is no entry or exit in this model and the number of firms is set to 1. There is no investment in the extensive margin here, therefore GDP is equal to consumption. Figure 6 shows the impulse responses from the imperfect competition model with the same markups as in our baseline model[20]. One can see that consumption falls by around 0.5 percent on impact which is about half the impact as compared to the baseline

[19] We use the accumulated impulse responses to assess the impact on Entry.
[20] Appendix A presents the model summary.

model. Energy imports, wages, profits and firm value fall. In this case as there is no entry, the ex post value of the firm adjusts on impact. Also, the baseline model gives us hump-shaped responses which the no entry model fails to do. As the no entry model is a one sector model with no extensive margin, the contractionary effect is much less pronounced. In the baseline model, both the production and entry sector contract in response to energy price shocks, so the effects on labor demand, wages and consumption are much bigger on impact and persist over time.

4.2 Energy in Cost of Entry

In this section, we extend the baseline model and assume entry costs consist of energy as well. In particular, we assume that the production technology for entry is the same as the consumption sector except for the firm specific productivity which we assume affects the consumption sector only. The consumer and the firms' problem remain the same. However we need to modify the entry costs to include energy. The costs for entry are now given as $C_{e,t} = f_{e,t} b w_t^{\alpha} p_{mt}^{1-\alpha}$. The production function for entry is $f_{e,t} N_{e,t} = (L_t^e)^{\alpha} (M_t^e)^{1-\alpha}$, where L_t^e, M_t^e represent the amount of labor and energy used in building $N_{e,t}$ firms. Since under our aggregation technique, the average firm can treated as the firm with average productivity we can write the factor market conditions as follows:

total labor supplied (L_t) must equal labor demand from the production and entry sector

$$L_t = L_t^c + L_t^e. \tag{34}$$

Aggregate labor demand for consumption (L_t^c) is the sum of firm level labor demand (l_t^c) for the production sector, $L_t^c = N_t l_t^c(\widetilde{z})$. Similarly aggregate labor demand for entry is

$$L_t^e = N_{e,t} l_t^e\left(\widetilde{z}\right) = \frac{\alpha N_{e,t} C_{e,t}}{w_t}. \tag{35}$$

The energy market conditions are given below; total energy usage is the sum of energy usage in production and entry

$$M_t = M_t^c + M_t^e. \tag{36}$$

Aggregate energy usage in production and entry can be obtained by summing over producing and entering firms, $M_t^c = N_t m_t^c(\widetilde{z})$,

$$M_t^e = N_{e,t} m_t^e(\widetilde{z}) = \frac{(1-\alpha) N_{e,t} C_{e,t}}{p_{mt}}. \tag{37}$$

The share of energy in GDP in the steady state is now given as

$$\frac{p_m M}{Y - p_m M} = \frac{(1 - S + \gamma)(1-\alpha)}{1 + \gamma - (1 - S + \gamma)(1-\alpha)} \tag{38}$$

which implies $\alpha = 0.9545$. The fixed cost in the steady state is given as

$$f = \frac{(1 - \beta(1-\delta))\, f_e}{b\beta(1-\delta_n)\left(\frac{\kappa - (\theta - 1)}{\theta - 1}\right)} \tag{39}$$

Figure 7.1 and 7.2 show the impulse responses with respect to an energy price shock. N_t, $\widetilde{v}_t$, $\widetilde{\rho}_t$ are predetermined and are not affected on impact. As in the baseline model, real wages must fall proportionately on impact to keep $\widetilde{\lambda_t^p}$ constant (the analysis of the production sector is the same as in the baseline model). One distinction from the baseline model is that the marginal cost of production and entry are same now, so the entry cost must also be predetermined with respect to shocks on impact (f_e is constant here). From the free entry condition, entry adjusts to keep the value of the firm $\widetilde{v}_t$ same on impact[21]. Note that production is less energy intensive now compared to the baseline model, so wages fall less on impact compared to the baseline model. However bulk of the adjustment happens through entry in this case while the response in firm value is lower than in the baseline model. As

[21]This can be easily seen by substituting for $\widetilde{\lambda_t^p}$ from equation 3, we can then write $\widetilde{v}_t = f_e \frac{\widetilde{\rho}_t}{\mu}$ which implies that $\widetilde{v}_t$ is only a function of $\widetilde{\rho}_t$, given that μ and f_e are both constant in the baseline model.

production is less energy dependent, firm profits fall less and the increase in the exit cut-off is lower in this case. This implies lower exit than in the baseline model. The returns to entry ($\widetilde{re}_{t+1} = \frac{\widetilde{v}_{t+1}+\widetilde{d}_{t+1}}{\widetilde{v}_t}$) falls more than in the baseline model as current firm value remains high compared to future returns. The larger decline in entry in this case allows households to smooth consumption further and the maximum drop is just 0.6 percent. Since each firm is producing less and there is less entry, energy usage in both the production sector (M_t^c) and entry sector (M_t^e) fall. As the entry sector contracts L_t^e falls on impact, households choose to reallocate labor from entry to production. However since all firms are producing less, labor demand is low in production and entry and it leads to a drop in real wages. Households supply less labor due to the fall in real wages. $GDP_t = C_t + \widetilde{v}_t N_{e,t}$, falls as both consumption and investment fall. The maximum fall in GDP is 0.9 percent due to a 10 percent increase in energy prices. Most of the drop in GDP is due to fall in investment in the extensive margin (around 6 percent) while response of consumption on impact is about 0.3 percent.

Over time the fall in entry leads to fewer firms N_t falls. But due to lower exit the decline in N_t is lower and less protracted compared to the baseline model. The adjustment process over time is similar to the baseline model.

5 Comparison with Exogenous Exit Models

In this section we compare models with endogenous and exogenous exits. The symmetric firm exogenous exit model cannot match our evidence of countercyclical exit and does not address the issue of firm selection which a model with firm heterogeneity and endogenous exit can. In addition, endogenous exit helps us generate a bigger amplification effect on output. As the entry decison is tied to exit as well i.e. anticipation of higher exit leads to lower entry, endogenous exit also helps us generate a more negative response of entry. Infact, models with exogenous exit rate as in Bilbiie, Melitz and Ghironi (2012) imply lower exit in response to negative shocks (as exit rate is constant, fewer producing firms imply fewer exits in future). This leads to a smaller response of entry in exogenous exit models as discussed in the results below.

As in the baseline model, we assume wages and prices are completely flexible and entry costs are specified in terms of labor costs only. For comparison across the two models, we assume the same average productivity for firms i.e. the firm level productivity z is taken to be the same as $\widetilde{z}$ in the heterogeneous firm model for steady state calculations. Note that because of our aggregation technique, aggregate variables are unaffected. The impulse responses are given in Figure 8.1 and 8.2. One can see that the endogenous exit model generates a much bigger impact on GDP compared to the exogenous exit model. The endogenous exit model is also successful in generating hump-shaped responses for consumption, real wages and firm value and while the decline on impact is smaller, the impact over time is bigger and more protracted.

The number of firms also shows a much bigger and protracted drop in the endogenous exit model due to two factors. Firstly, higher energy prices cause higher exit in this model, secondly entry is also lower in this case. Thus when entry costs are specified in terms of labor costs, we need endogenous exits to capture the effects of oil price shocks on the extensive margin. The model with exogenous exit does not imply a significant response of the extensive margin and is unable to match the negative impact on firm entry or higher exit post an oil price shock. The endogenous exit model successfully captures both these effects and additionally suggests that oil price shocks cause reallocation towards more productive firms due to increase in the productivity cut-off required for survival. This is again well documented as the "cleansing effect of recessions" where resources are allocated from less productive to more productive firms (See Davis and Haltiwanger 1990, 1992, 1999; Caballero and Hammour, 1994). From this perspective, oil price shocks can be productivity enhancing which is in contrast to the standard approach of treating oil price shocks as negative productivity shocks. Furthermore, as entry is more responsive in the model with endogenous exits, the model is consistent with evidence presented in Lee and Mukoyama (2012) who study selection at entry and exit margins and find that selection at the entry margin to be dominant over the business cycle.

6 Model with Monetary Policy: Role of Sticky Prices and Sticky wages

In this section, we introduce sticky prices and sticky wages. The role of sticky wages is particularly important as in the baseline model complete flexibility of wages implies that real wages fall when energy prices increase such that marginal costs remain the same in equilibrium. However, if wages are sticky, real wages may not fall proportionally to compensate for the increase in energy prices and the effects of energy price shocks may be even bigger. This is because when wages are sticky profits fall much more on impact, in addition entry costs remain high. High entry costs and lower returns to entry imply that higher oil prices cause a big drop in entry on impact. We model sticky prices and sticky wages following Rotemberg (1982)[22]. Firms face a quadratic cost of adjusting prices over time. The real cost of price adjustment facing an individual firm producing variety (z) is as follows

$$pac_t(z) = \frac{\Psi_p}{2}\left[\frac{p_t(z)}{p_{t-1}(z)} - 1\right]^2 \frac{p_t(z)}{P_t} y_t^c(z), \qquad \Psi_p \geqslant 0. \tag{40}$$

The profit function for each firm must account for these adjustment costs, so accordingly profit for each variety is given as

$$d_t(z) = \rho_t(z)y_t(z) - w_t l_t(z) - p_{mt}m_t(z) - \frac{\Psi_p}{2}\left[\frac{p_t(z)}{p_{t-1}(z)} - 1\right]^2 \rho_t(z)y_t^c(z).$$

The first order condition with respect to $p_t(z)$ is given below

$$p_t(z) = \mu_t(z)P_t\lambda_t^p(z). \tag{41}$$

Firms set a markup $\mu_t(z)$ over prices which can be written as

[22] This approach of modeling nominal rigidities is common in the entry literature (Bilbiie, Ghironi and Melitz (2007), Lewis (2009), Lewis and Poilly (2012) etc.).

$$\mu_t(z) = \frac{\theta}{\theta - 1\left[1 - \frac{\Psi_p}{2}\pi_t(z)^2\right] + \Psi_p \Upsilon_t(z)}, \tag{42}$$

where $\pi_t(z) = \frac{p_t(z)}{p_{t-1}(z)} - 1$ and

$$\Upsilon_t(z) = \pi_t(z)[\pi_t(z)+1] - E_t\left[Q_{t,t+1}\pi_{t+1}(z)[\pi_{t+1}(z)+1]^2 \frac{y^c_{t+1}(z)}{y^c_t(z)}\frac{P_t}{P_{t+1}}\right]. \tag{43}$$

In the absence of nominal price rigidities ($\Psi_p = 0$) or if prices remain constant the markup $\mu_t(z)$ reduces to $\frac{\theta}{\theta-1}$. Using our aggregation method, the aggregate price adjustment costs can be expressed as:

$$PAC_t = N_t pac_t(\widetilde{z}) = \frac{\Psi_p}{2}(\pi_t)^2 Y^c_t \tag{44}$$

Using $Y^c_t = N_t \rho_t(\widetilde{z}) y^c_t(\widetilde{z})$ the markups for the average firm are as follows

$$\mu_t(\widetilde{z}) = \frac{\theta}{\begin{array}{c}\theta - 1\left[1 - \frac{\Psi_p}{2}(\pi_t(\widetilde{z}))^2\right] + \Psi_p \\ \left[\pi_t(\widetilde{z})[\pi_t(\widetilde{z})+1] - E_t(Q_{t,t+1}\pi_{t+1}(\widetilde{z})[\pi_{t+1}(\widetilde{z})+1]\frac{Y^c_{t+1}}{Y^c_t}\frac{N_t}{N_{t+1}})\right]\end{array}} \tag{45}$$

We introduce sticky wages in a similar fashion. All households are allocated across the unit interval and supply a unique type of labor. Labor supplied by household h is denoted by $L_t(h)$. This allows for labor differentiation and the representative household has market power to set nominal wage $W_t(h)$. The wage adjustment cost $wac_t(h)$ is given as follows where Ψ_W is the cost of adjusting wages in terms of the consumption bundle incurred by households.

$$wac_t(h) = \frac{\Psi_W}{2}\left[\frac{W_t(h)}{W_{t-1}(h)} - 1\right]^2 \frac{W_t(h)}{P_t} \qquad \Psi_W \geqslant 0. \tag{46}$$

The household of type h maximizes expected lifetime utility,

$$E_t[\sum_{i=0}^{\infty}\beta^i U(C_{t+i}(h), L_{t+i}(h))],$$

where β is the subjective discount factor, $C_t(h)$ refers to consumption and $L_t(h)$ is labor supply. The Period Utility Function is given as

$$U(C_t(h), L_t(h)) = \ln C_t(h) - \frac{\chi(L_t(h))^{1+1/\varphi}}{1+1/\varphi},$$

where $\chi > 0$ is the weight of disutility of labor and $\varphi \geqslant 0$ represents the Frisch elasticity of labor supply to wages and the intertemporal elasticity of substitution in labor supply. The households income consists of labor earnings net of wage setting costs, the return from firm equity and interest income on bonds. The expenditure side consists of consumption spending and future share and bond holdings. The households budget constraint is

$$\begin{aligned}\widetilde{v}_t(N_t + N_{e,t})x_{t+1}(h) + C_t(h) + \frac{B_{t+1}(h)}{P_t} \;&=\; (\widetilde{d}_t + \widetilde{v}_t)N_t x_t(h) + \frac{W_t(h)}{P_t}L_t(h) - wac_t(h) + \\ &\quad (1+i_{t-1})\frac{B_t(h)}{P_t}, \qquad (47)\end{aligned}$$

where i_{t-1} is the nominal interest rate on bonds between periods $t-1$ and t. Additionally because of labor differentiation the following condition also has to be satisfied

$$L_t(h) = \left(\frac{W_t(h)}{W_t}\right)^{-\varepsilon_W} L_t$$

where $W_t = \left[\int_0^1 W_t(h)^{1-\varepsilon_W} dh\right]^{\frac{1}{1-\varepsilon_W}}$ and $L_t = \left[\int_0^1 L_t(h)^{\frac{\varepsilon_W - 1}{\varepsilon_W}} dh\right]^{\frac{\varepsilon_W}{\varepsilon_W - 1}}$ are aggregate nominal wages and labor and $\varepsilon_W > 0$ is the elasticity of substitution. The households optimality conditions can be derived by maximizing the utility function subject to the budget constraint and the labor differentiation equation. The first order conditions with respect to $C_t(h)$, $B_{t+1}(h), W_t(h), x_{t+1}(h)$ are as follows

$$C_t(h): \qquad \frac{1}{C_t(h)} = \lambda_t, \tag{48}$$

$$B_{t+1}(h): \ \frac{1}{C_t(h)} = \beta E_t\left[\frac{1+i_t}{1+\pi^c_{t+1}}\frac{1}{C_{t+1}(h)}\right] \tag{49}$$

where $\pi^c_{t+1} = \frac{P_{t+1}}{P_t} - 1$,

$$x_{t+1} : \widetilde{v_t} = \beta\frac{N^A_t}{N_t}E_t[\frac{C_t}{C_{t+1}}(\widetilde{d_{t+1}} + \widetilde{v_{t+1}})], \tag{50}$$

$$W_t(h): \ \frac{W_t(h)}{P_t} = \chi L_t(h)^{\frac{1}{\varphi}}C_t(h)\left(\frac{\varepsilon_W}{\varepsilon_W - 1}\right) + \Psi_W\frac{\Upsilon_t(h)}{L_t(h)} \tag{51}$$

where

$$\begin{aligned}\Upsilon_t(h) \ &= \ -\left[\frac{1}{\varepsilon_W - 1}\pi^W_t(h)(1+\pi^W_t(h))w_t(h)\right] - \\ &\left[\frac{1}{2(\varepsilon_W - 1)}\left(\pi^W_t(h)\right)^2 w_t(h)\right] + \beta E_t\left[\frac{w_{t+1}(h)}{\varepsilon_W - 1}\frac{C_t(h)}{C_{t+1}(h)}\pi^W_t(h)(1+\pi^W_t(h))\right]\end{aligned} \tag{52}$$

and $\pi^W_t(h) = \frac{W_t(h)}{W_{t-1}(h)} - 1$.

Assuming symmetry and aggregating over households the real wage can be written as

$$w_t = \chi L_t^{\frac{1}{\varphi}}C_t\left(\frac{\varepsilon_W}{\varepsilon_W - 1}\right) + \Psi_W\frac{\Upsilon_t}{L_t} \tag{53}$$

The aggregate market resource constraint is

$$Y^c_t = C_t + p_{mt}M_t + PAC_t + wac_t \tag{54}$$

The monetary policy rule is specified as,

$$\widehat{I}_t = \tau_\pi\widehat{\pi}_t + \tau_I\widehat{I}_{t-1} + \eta_t \tag{55}$$

where the central bank adjusts the interest rate in response to inflation and last periods interest rate. η_t is assumed to be a white noise shock.

Therefore, the additional equations required are the resource constraint, the new markup equation and the monetary policy rule. The labor optimality condition is replaced by the wage equation. All the other equations remain the same as in the baseline model.

The productivity threshold can be derived as in the baseline model. Note that the markups are firm specific now and we have to include price adjustment costs. However, both these factors do not affect the log-linearized version of the equation.

Starting from the cut-off firms profit, sum of future profits are zero by definition for this firm. Therefore,

$$\sum_{j=1}^{\infty} Q_{t,t+j}\left(\rho_{t+j}(z_t^*)y_{t+j}^c(z_t^*)[1-1/\mu_{t+j}^*(z_t^*)] - fbw_{t+j}^{\alpha}p_{mt+j}^{1-\alpha} - pac_{t+j}(z_t^*)\right) = 0. \quad (56)$$

Following the same steps as before, we get

$$\sum_{j=1}^{\infty} Q_{t,t+j}\left[\left(\mu_{t+j}^*(z_t^*)\lambda_{t+j}^p(\widetilde{z})\frac{\widetilde{z}}{z_t^*}\right)^{1-\theta} Y_{t+j}^c[1-1/\mu_{t+j}^*(z_t^*)] - fbw_{t+j}^{\alpha}p_{mt+j}^{1-\alpha} - pac_{t+j}(z_t^*)\right] = 0.$$

Log-linearizing around the steady state we get[23],

$$\widehat{z_t^*} = \overline{\beta}\widehat{z_{t+1}^*} + (1-\overline{\beta})\widehat{\lambda_t^p(\widetilde{z})} + (1-\theta)^{-1}\widehat{Y_{t+1}^c} - (1-\theta)^{-1}\widehat{X_{t+1}} \quad (57)$$

where $X_{t+1} = fbw_{t+1}^{\alpha}p_{mt+1}^{1-\alpha}$, $\widehat{X_{t+1}} = \alpha\widehat{w_{t+1}} + (1-\alpha)\,\widehat{p_{mt+1}}$

Parameters and calibration values are given in Table 3 below. The additional parameters such as price stickiness Ψ_p, elasticity of substitution for labor ε_W, interest rule coefficient τ_π and interest rate smoothing coefficient τ_I are set to be 77, 3, 0.3 respectively following Lewis (2009). We set the wage stickiness parameter Ψ_W to be 10.

The impulse responses are given in Figure 9.1 and 9.2. Introduction of sticky

[23]The details of this derivation is given in the appendix.

wages leads to a much larger drop in GDP compared to the baseline model. A 10 percent rise in energy prices causes a 7 percent drop in GDP on impact[24]. This is because of extreme sensitivity of entry with respect to energy shocks. The decline in consumption is also bigger, though the big drop in entry helps in smoothing consumption (the drop in consumption is 0.6 percent on impact). Exit however depicts a surprising pattern. In this case, we get a decline in exit as the productivity cut-off falls. This is again attributable to the huge response of entry. As entry falls the number of firms dips dramatically in the future which leads to temporarily higher profits for the surviving firms. Average firm production increases sharply after the initial decline. The exit-cutoff is forward looking, anticipation of higher returns in future leads to lower z_t^* on impact. This is also the reason behind the marginal drop in exit on impact and then the further decline due to higher returns for existing firms.

The big drop in number of surviving firms leads to lower labor demand and wages dip further to a decline of 0.9 percent though the initial decline in wages is only 0.4 percent due to wage stickiness. As the current share price $\widetilde{v}_t$ is low returns to entry are very high and this leads to higher entry. Households allocate labor to the entry sector and reduce labor in production (note even though each firm is producing less, we have very few firms now, so aggregate labor in production is lower). Over time as higher entry and lower exit increase the number of firms, returns to entry falls and stabilizes at the old steady state. Note that the returns to entry remain higher than the old steady state for most of the transition period. This leads to slow down of entry till we are back at the old steady state. The exit-cut off also increases and exit increases to the old steady state value. Even though entry and exit move in opposite directions, the response of entry is key here as it dominates the exit response.

Therefore the results emphasize the importance of the extensive margin and sticky wages[25] in amplifying the response of energy price shocks in theoretical models. In

[24] This result is in line with the entry literature. For example, Lewis (2009) shows a 15 percent increase in output with respect to monetary shocks (Ψ_w is taken to be 77 in her model).

[25] Even though the model features sticky prices as well, it is sticky wages which is of primary importance. The impulse responses from the model with only sticky prices are only marginally different from the baseline model. The results are given in the appendix.

fact, the more rigid nominal wages are the bigger is the impact on GDP[26].

Therefore, based on our analysis, the model with entry and exit is better able to match the empirical patterns observed in the data. However, the models with sticky wages overestimate the impact on entry. To rectify this issue, congestion cost in entry may be considered. This approach as shown in Lewis and Poilly (2012) imply that only a fraction of entrants are successful. Another way out may be the introduction of capital, which provides households another instrument for intertemporal reallocation of resources. Both of these factors may dampen the excessive impact of shocks on entry. It may also help in getting the correct response of exit in the endogenous exit model with sticky wages.

Thus, comparing the impulse responses across the models, one can see that the extensive margin is an important channel for aggregate shocks and amplifies the effect of oil price shocks. The baseline DSGE model predicts the right sign in terms of response of entry as well as exit and also reflects the fact that entry, exit are much more responsive to energy price shocks compared to GDP. The impulse responses from the VAR models imply that the responses of entry and exit are similar in magnitude. This is also captured well in the baseline DSGE model while the model with sticky wages over estimates the response of entry and predicts the wrong sign for exit. The VAR model understates the response of entry to energy price shocks, as it does not include introduction or closing of new product lines in existing firms. Since in the DSGE model each product corresponds to a particular firm, it is expected that the responses will be bigger in the theoretical model than in the data or number of firms alone. To capture this effect in an empirical setting, we need aggregate data on product development and destruction which is currently unavailable. We think that given the evidence in this paper, the effects of energy price shocks would be even stronger in a product level study. However, the DSGE model fails to predict the "u" shaped responses in the data. This suggests lags in setting up firms or exiting the market.

[26] This is not to imply that the extensive margin is not important and it is sticky wages which is driving this result. Infact, introduction of sticky wages without an extensive margin leads to no amplification and the impulse responses are similar to the no entry model oulined above. The impulse responses are given in the appendix.

7 Conclusion

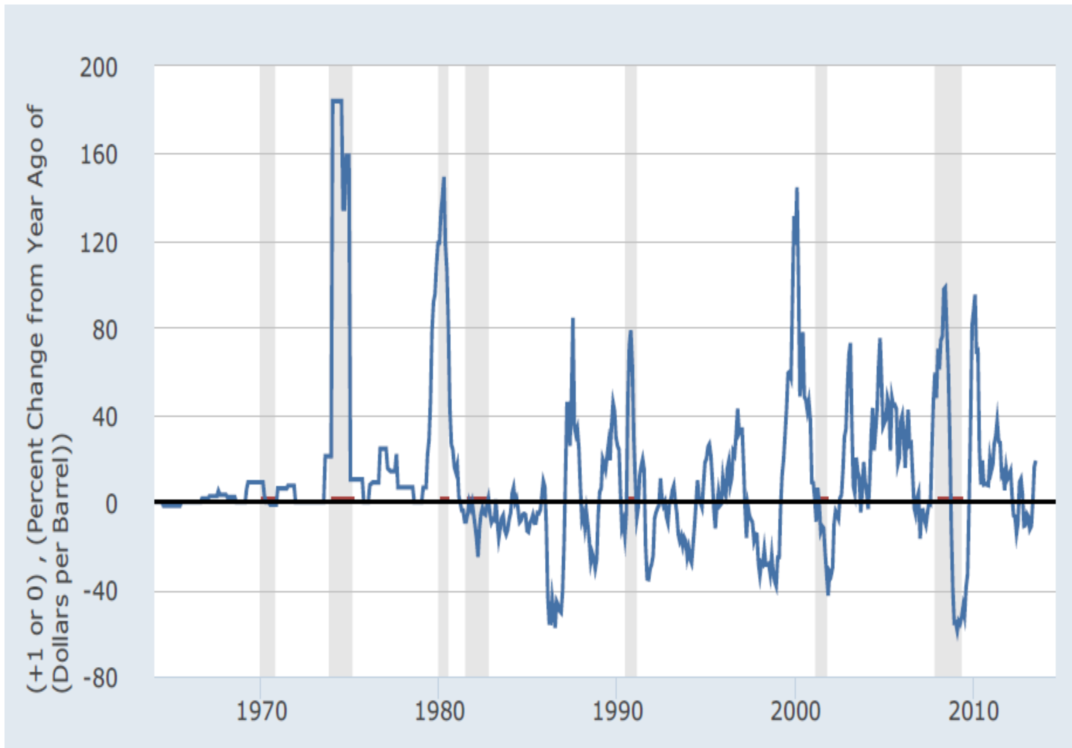
This paper builds a framework to incorporate energy price shocks in a DSGE model with endogenous firm entry and exit. We show that the extensive margin is an important channel for propagation of shocks and magnifies the effect of energy price increases. This is in contrast to typical RBC models that imply only small effects of oil price changes. Our approach shows that even without the standard channels, amplification is possible by endogenizing the extensive margin. Our model also successfully captures the pattern of firm entry and exit observed in U.S. data. Additionally, due to firm heterogeneity, the model can explain selection patterns over the business cycle. Depending on the interaction between entry and exit in these models, oil price shocks can raise firm level productivity.

In the baseline model we generate both lower entry and higher exit in response to oil price shocks. However the drop in entry is not high enough to insulate existing firms and firm level productivity increases. In the model with sticky wages oil price shocks cause a much bigger drop in entry and in that case firm level productivity falls and exit actually declines in response to an oil price shock. This is consistent with the literature on creative destruction and the productivity enhancing effects of recessions. We are the first to demonstrate similar effects for oil price shocks in a DSGE framework.

In the empirical section of the paper, we use VAR models to study the impact of oil price shocks on firm entry and exits. Our results confirm that oil price shocks have a significant negative effect on firm entry and cause higher firm exits. Furthermore, firm entry and exit are much more responsive to oil price shocks compared to GDP.

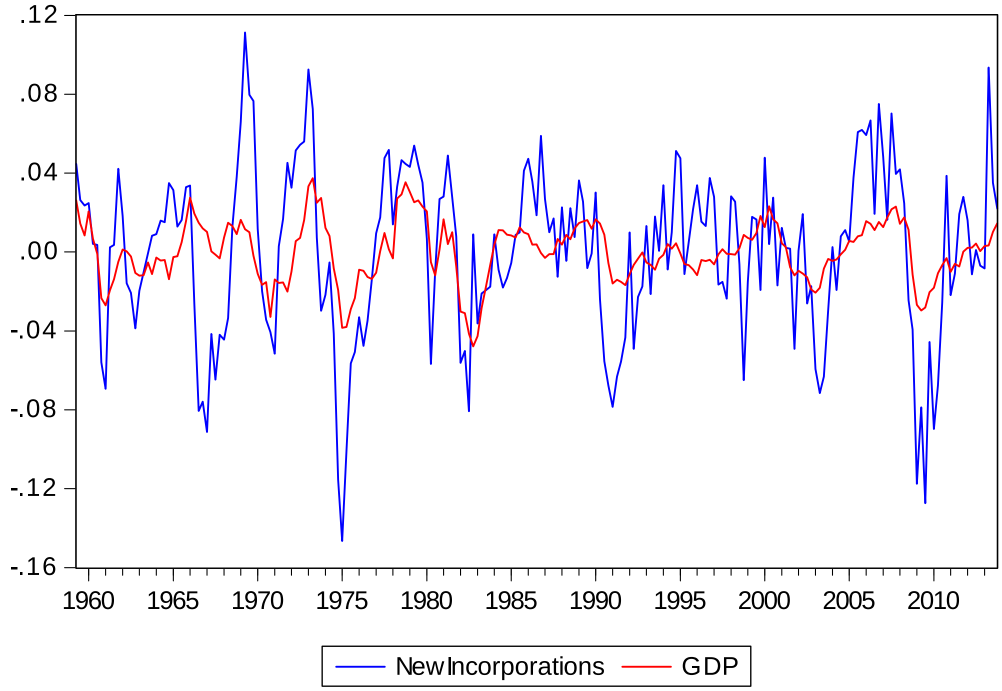
Thus the evidence presented in this paper highlights an important channel of transmission for oil price shocks which has been over looked in the literature. Some directions for future research are introduction of capital and entry adjustment costs which may improve the predictions of the model.

Figure 1.1: Oil Price Growth Rate and U.S. Recessions



Notes: Graph shows NBER based recession indicators (shaded areas) and West Texas Intermediate Spot Oil Price. Source: St. Louis Fed

Figure 1.2: New Incorporation, Net Business Formation and GDP



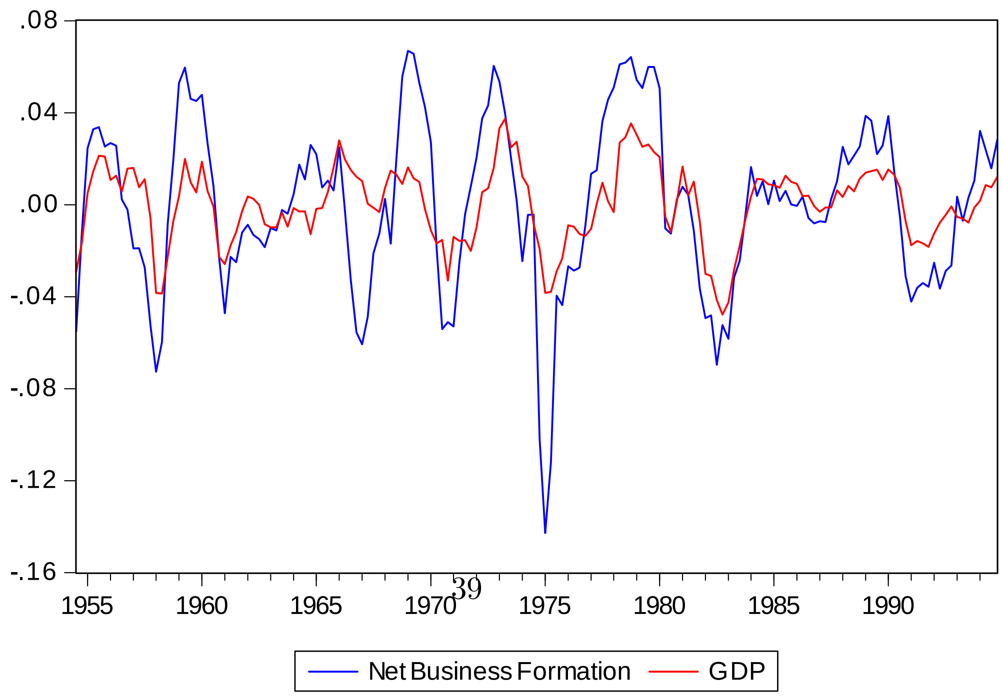


Figure 1.3: Industrial and Commercial Failures, Establishment Deaths and GDP

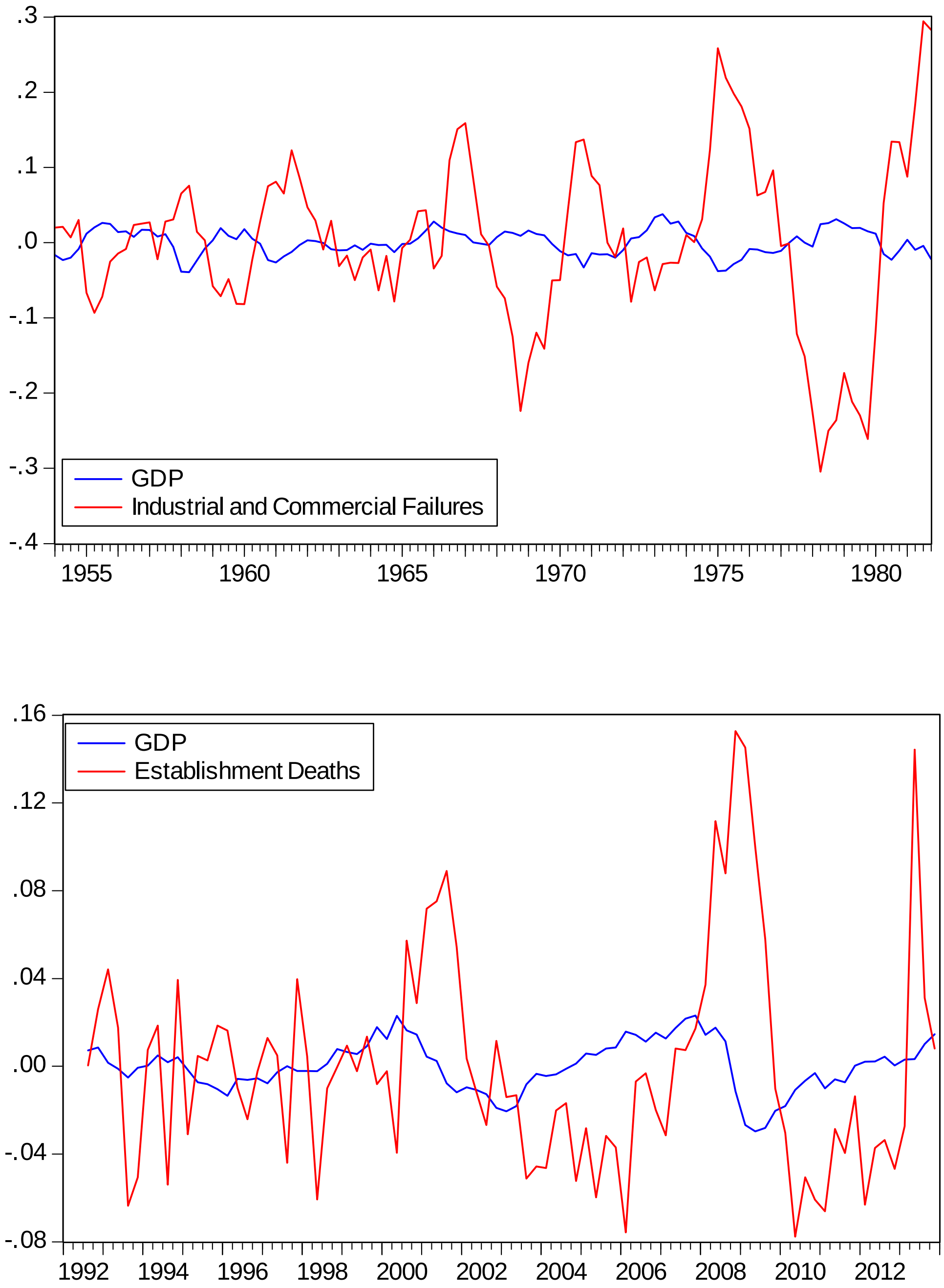
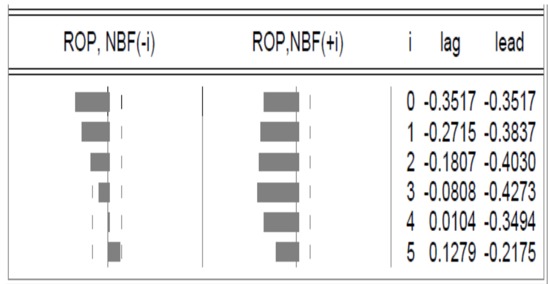
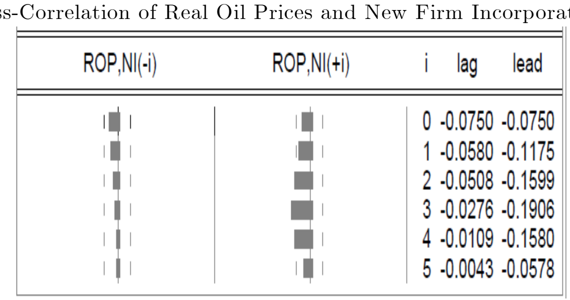


Figure 2

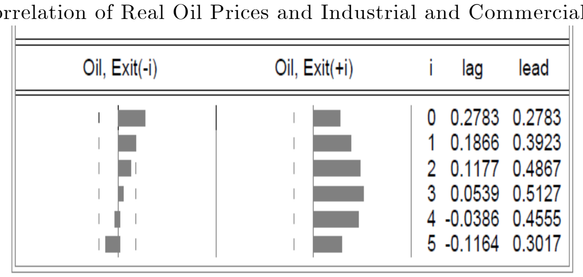
Cross-Correlation of Real Oil Prices and Net Business Formation



Cross-Correlation of Real Oil Prices and New Firm Incorporations



Cross-Correlation of Real Oil Prices and Industrial and Commercial Failures



Cross-Correlation of Real Oil Prices and Establishment Deaths

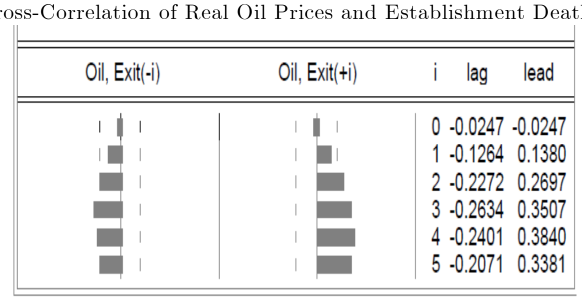
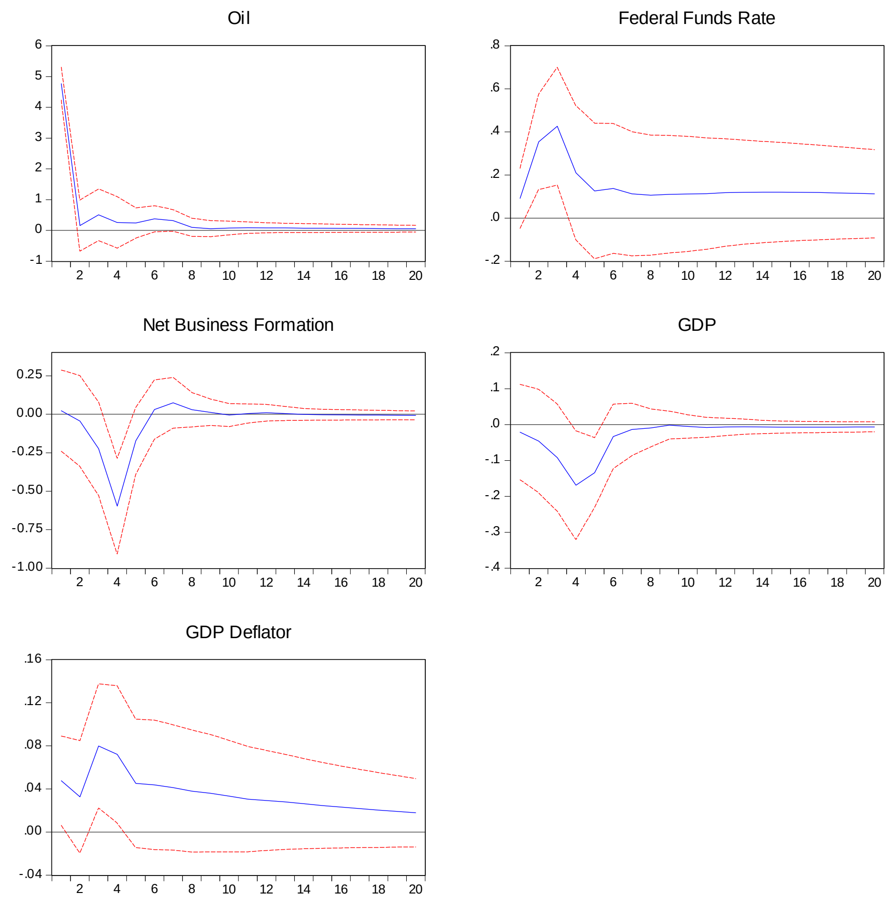


Table 1

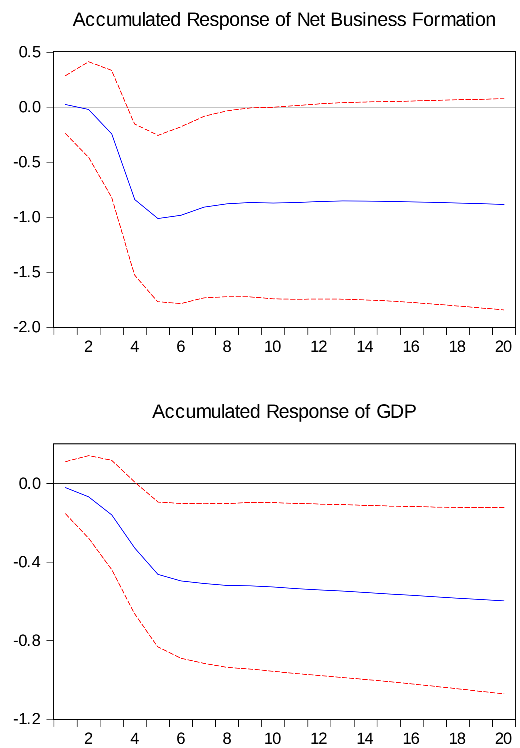
Variable	Data Source/Series	VAR variables
Oil Price	BLS/WPU0561	$OIL = x_t^{\#}$
Entry	SCB/BLS	NE=$100 * ln(Entry_t/Entry_{t-1})$
Real GDP	BEA	$GDP = 100 * ln(GDP_t/GDP_{t-1})$
DEF	BEA Implicit GDP Deflator	$DEF = 100 * \ln(DEF_t/DEF_{t-1})$
Fed Funds rate	Board of Governors, FEDFUNDS	$ff = FederalFundsrate$
Exit	BLS/SCB	$NX = 100 * ln(Exit_t/Exit_{t-1})$

Figure 3.1: Impulse Responses to Hamilton Measure of Oil Prices



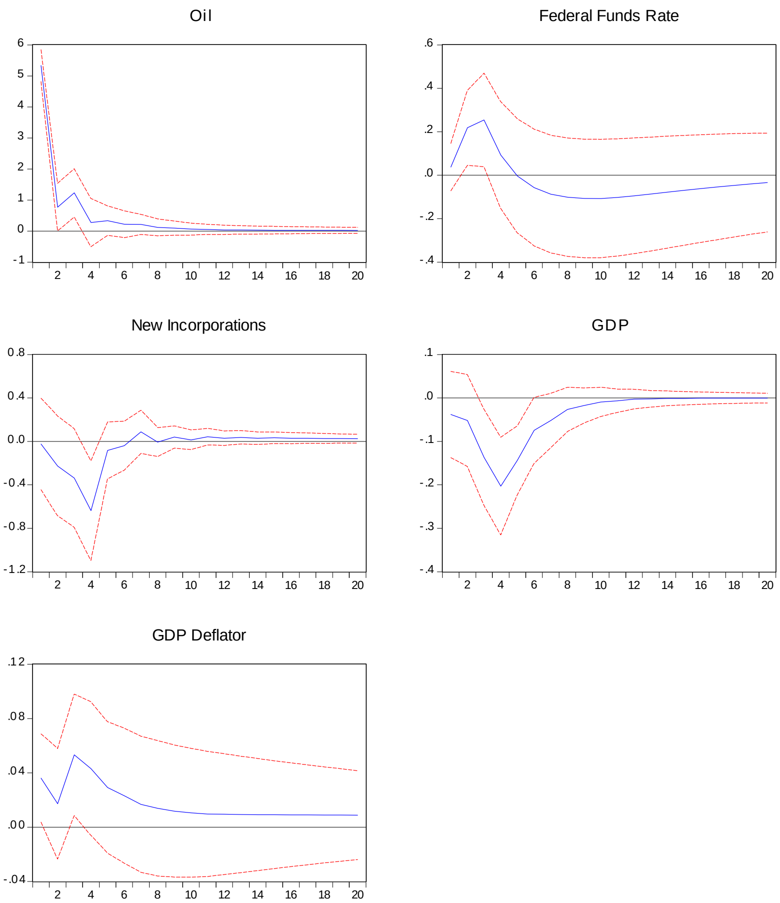
Notes: The figures above show impulse responses to a one standard deviation shock in oil prices. The first variable in the Cholesky decomposition is the Hamilton variable identifying the oil price shock. The ordering of the other variables are not critical for our analysis.The vertical axis shows the growth rate for all variables except federal funds rate. The horizontal axis shows time in quarters. The error bands represent 95% confidence intervals.

Figure 3.2: Accumulated Impulse Responses to Hamilton measure of Oil Prices



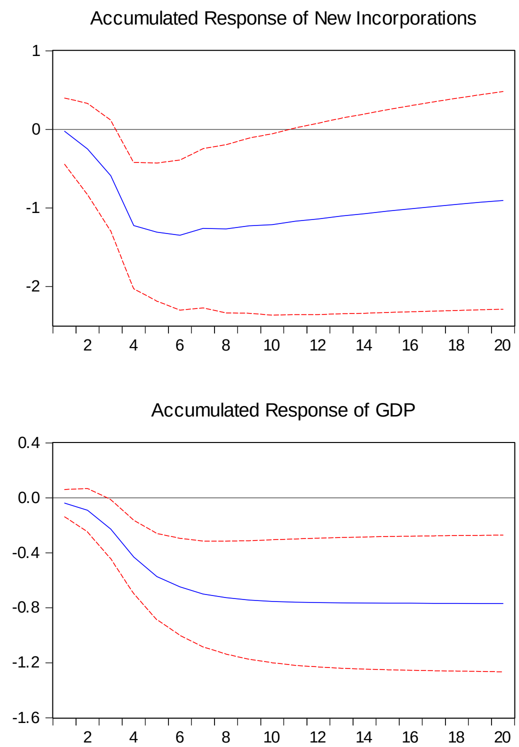
Notes: The impulse responses from the above VAR are accumulated to get the impact on levels along the vertical axis. The horizontal axis shows time in quarters. The 95% confidence intervals are shown in the graph.

Figure 3.3: Impulse Responses to Hamilton Measure of Oil Price



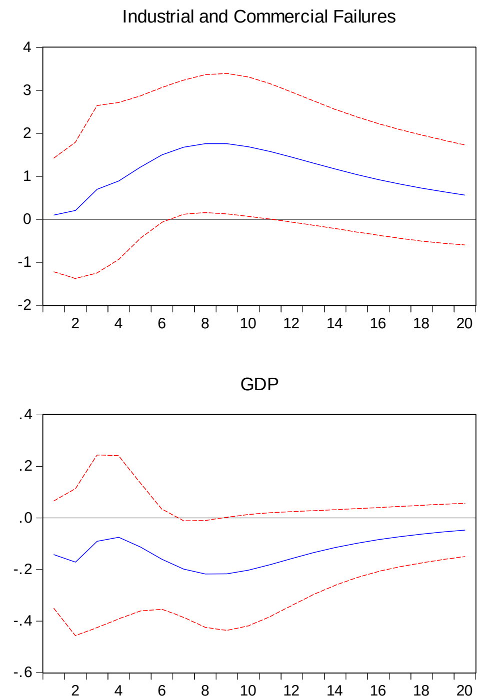
Notes: See notes to Fig 3.1.

Figure 3.4: Accumulated Responses to Hamilton Measure of Oil Price



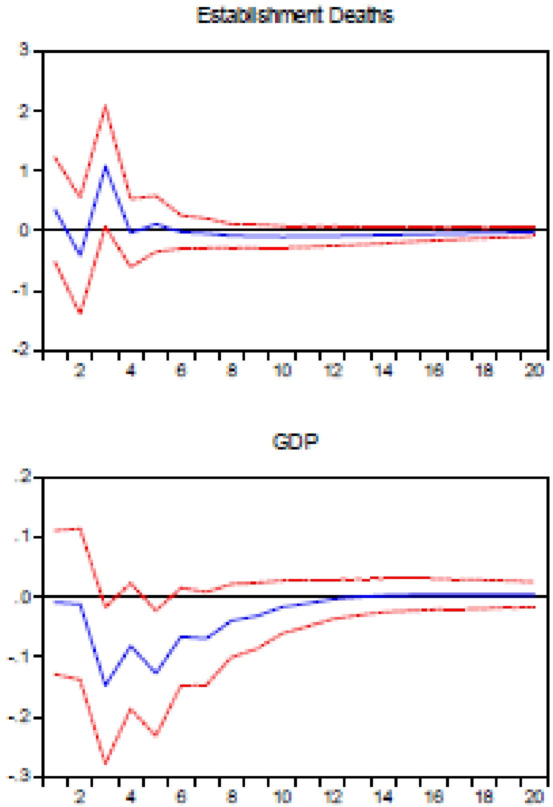
Notes: See notes to Fig 3.2.

Figure 4.1: Impulse Responses to Hamilton Measure of Oil Prices



Notes: The figures above show impulse responses to a one standard deviation shock in oil prices. The first variables the Cholesky decomposition is the Hamilton variable identifying the oil price shock. The ordering of the other variables are not critical for our analysis. The vertical axis shows growth rates, the horizontal axis shows time in quarters. The error bands represent 95% confidence intervals.

Figure 4.2: Impulse Responses to Hamilton Measure of Oil Prices

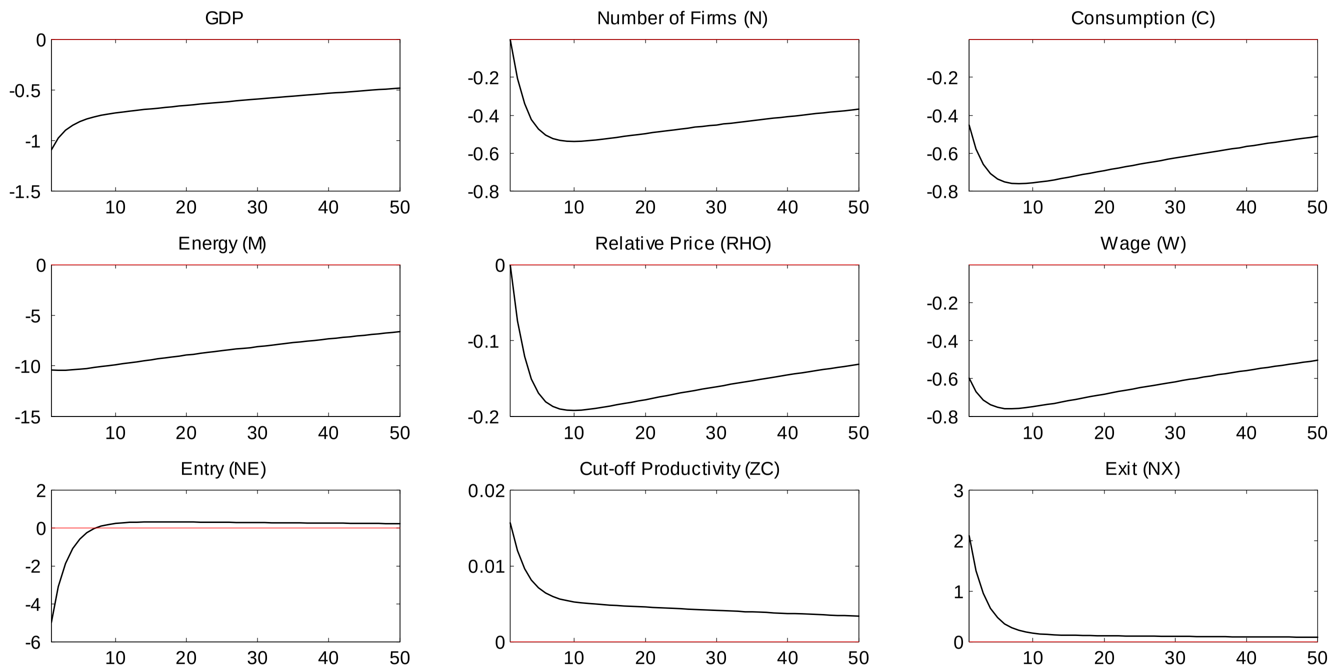


Notes: See notes to Figure 4.1.

Table 2: Calibrated Parameters

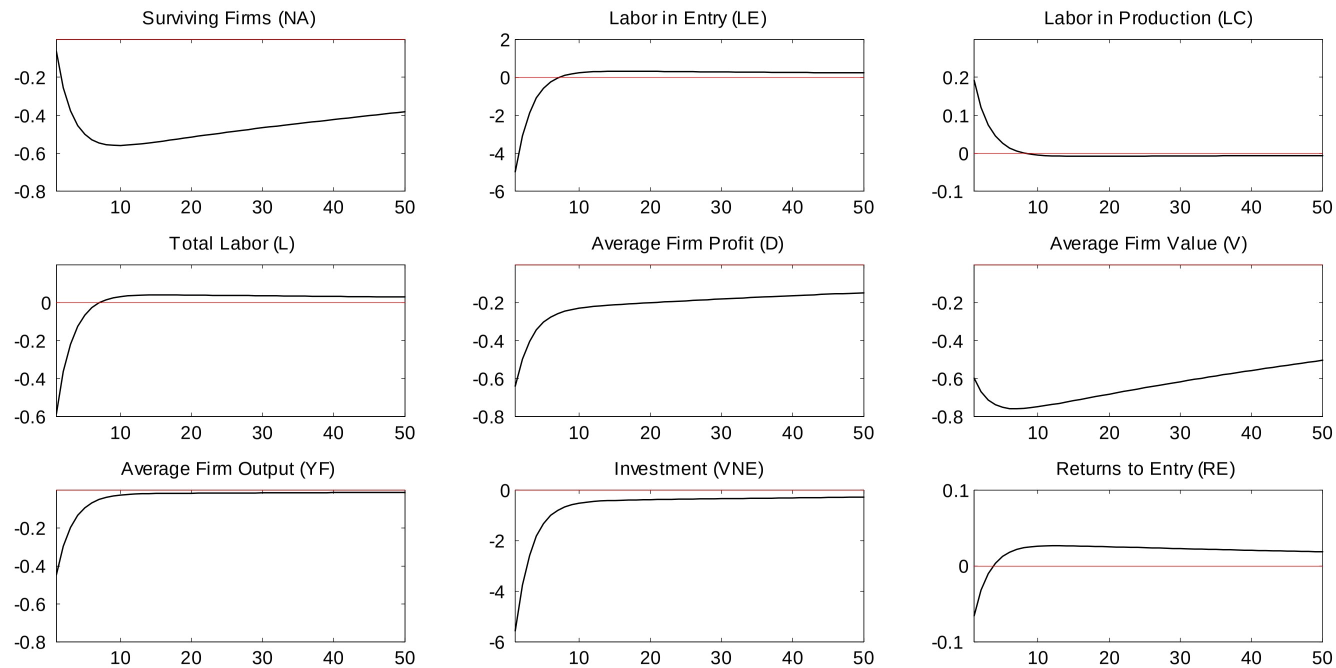
Parameter	Value	Interpretation
β	0.99	Discount factor
θ	3.8	Elasticity of substitution
φ	4	Frisch elasticity
χ	0.924271	Disutility of labor
f_e	1	Entry cost
α	0.9437	Share of labor
δ	0.029	Exit in the steady state
$z_{\min}$	1	Lower bound of Pareto Distribution
κ	4	Shape parameter of Pareto Distribution
σ_{m_Z}	0.127	Standard deviation of energy price shock
ϕ_m	0.99	Persistence of Energy Price Shock

Figure 5. 1: Impulse Responses to a 10% p_m shock Baseline Model, $\alpha = 0.9437$



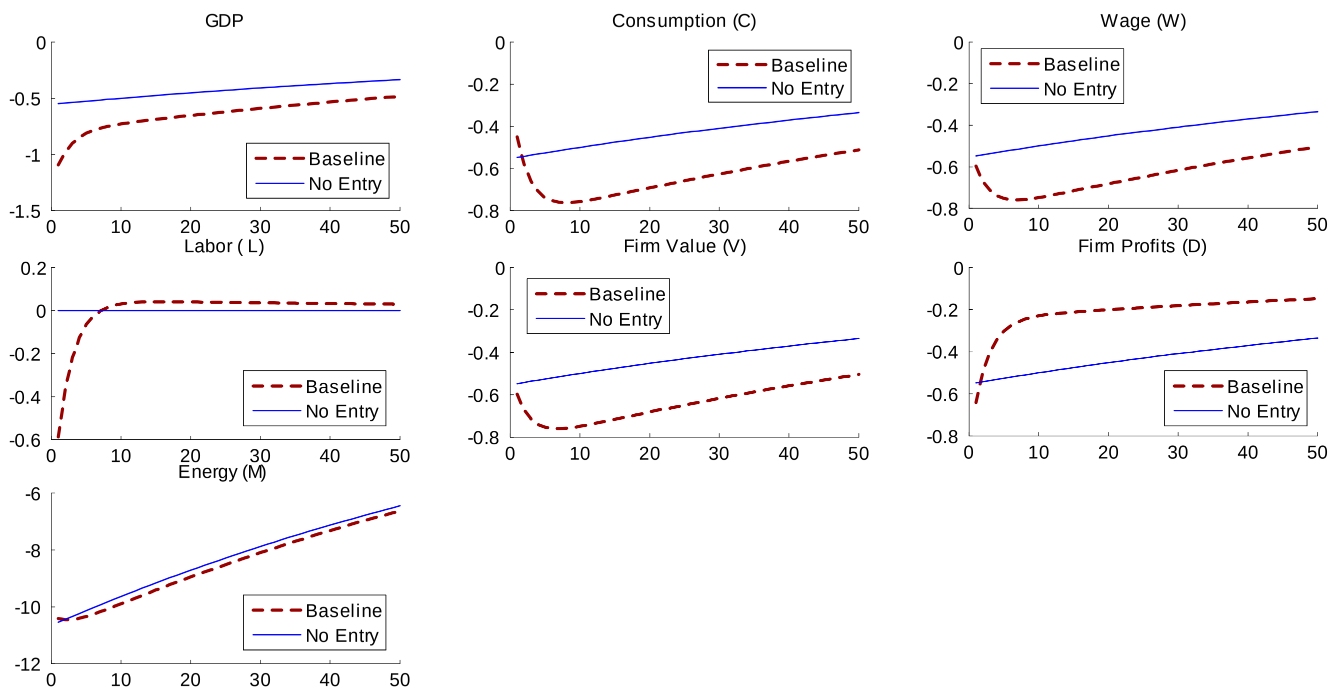
Notes: All impulse responses are scaled to a 10 percent increase in real price of energy. The horizontal axis represents time in quarters. The y axis shows percent deviations of variables from the steady state.

Figure 5. 2: Impulse Responses to a 10% pm shock Baseline Model, $\alpha = 0.9437$



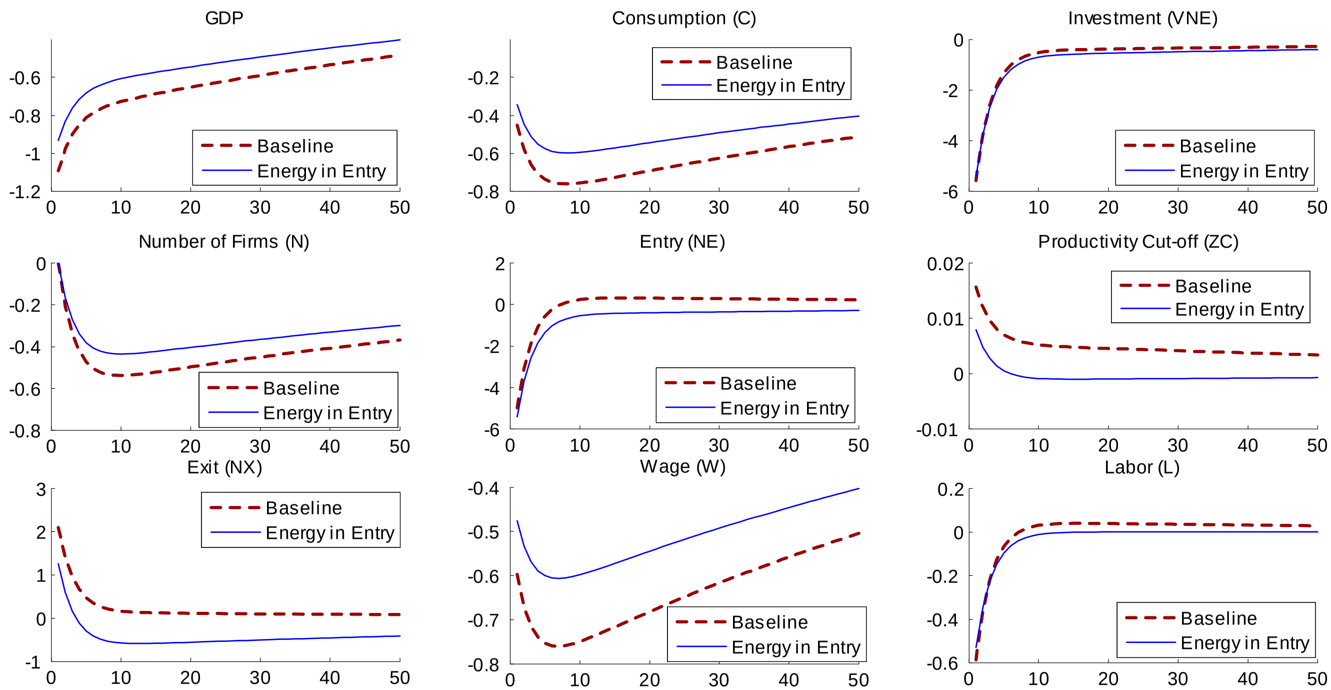
Notes: All impulse responses are scaled to a 10 percent increase in real price of energy. The horizontal axis represents time in quarters. The y axis shows percent deviations of variables from the steady state.

Figure. 6: Impulse Responses to a 10% pm shock Baseline Model, No Entry



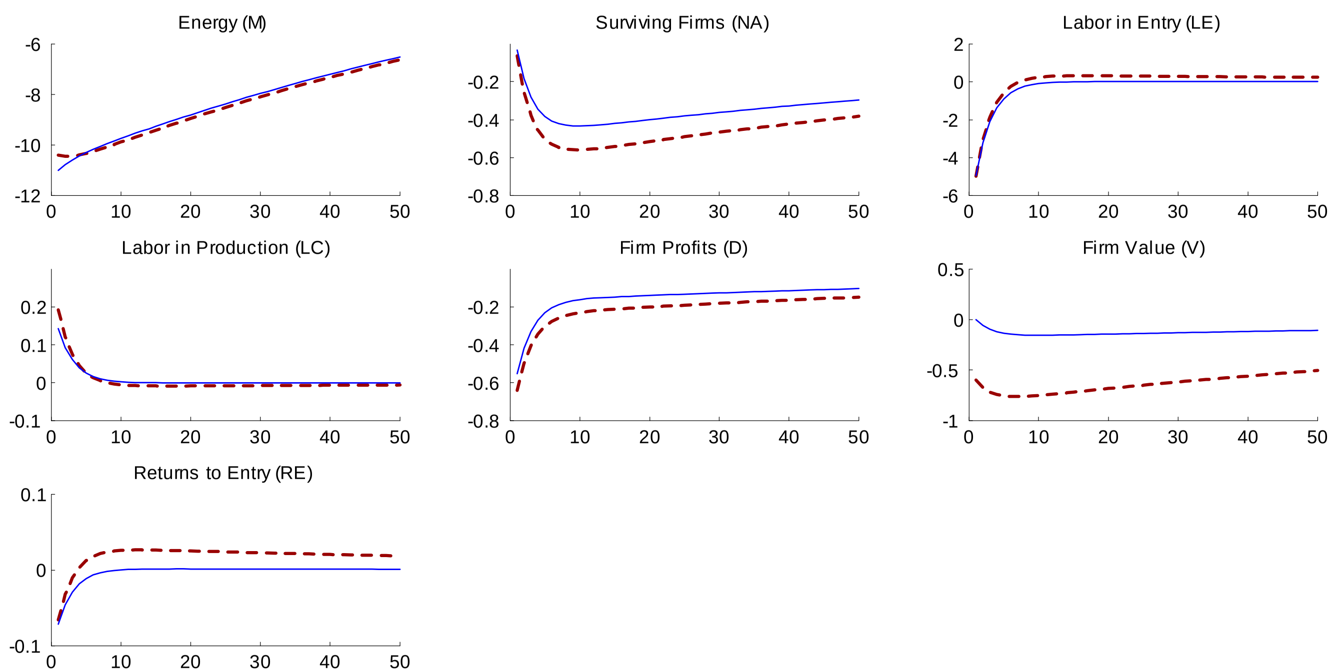
Notes: See notes to Figure 5.

Figure 7. 1: Impulse Responses to a 10% pm shock Baseline Model, Energy in Entry Model



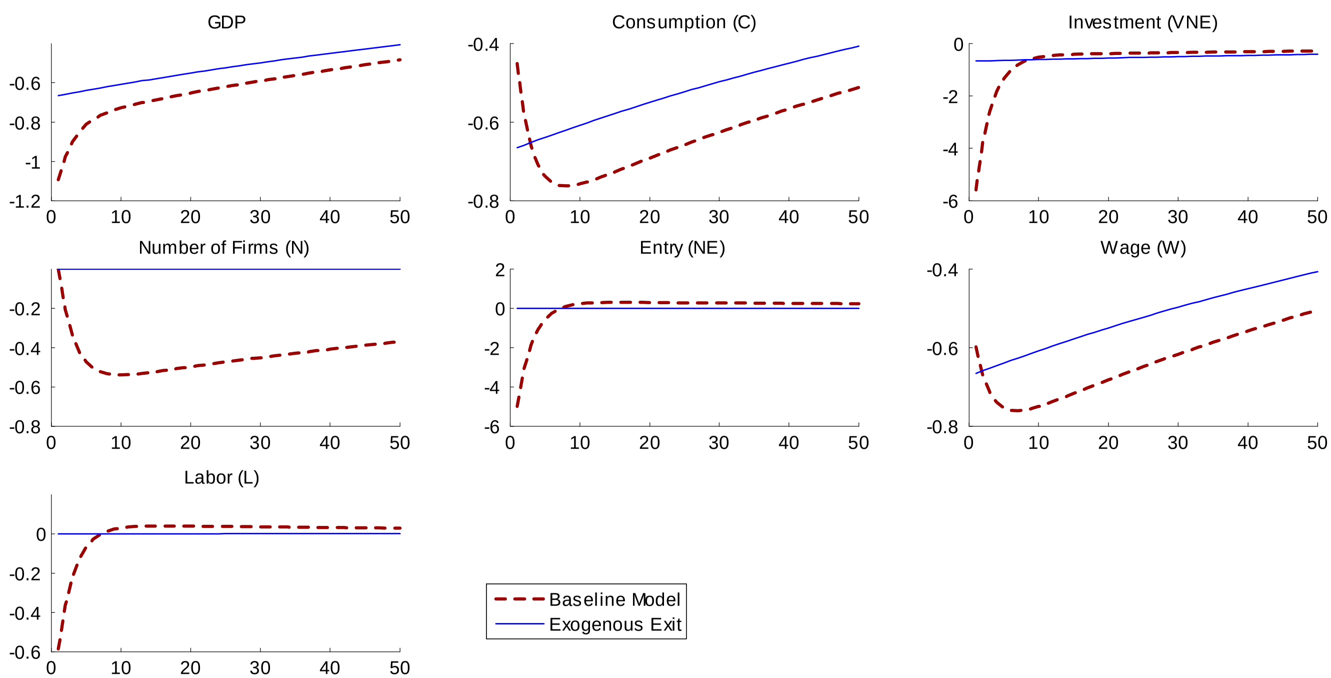
Notes: See notes to Figure 5.

Figure 7. 2: Impulse Responses to a 10% pm shock Baseline Model, Energy in Entry Model



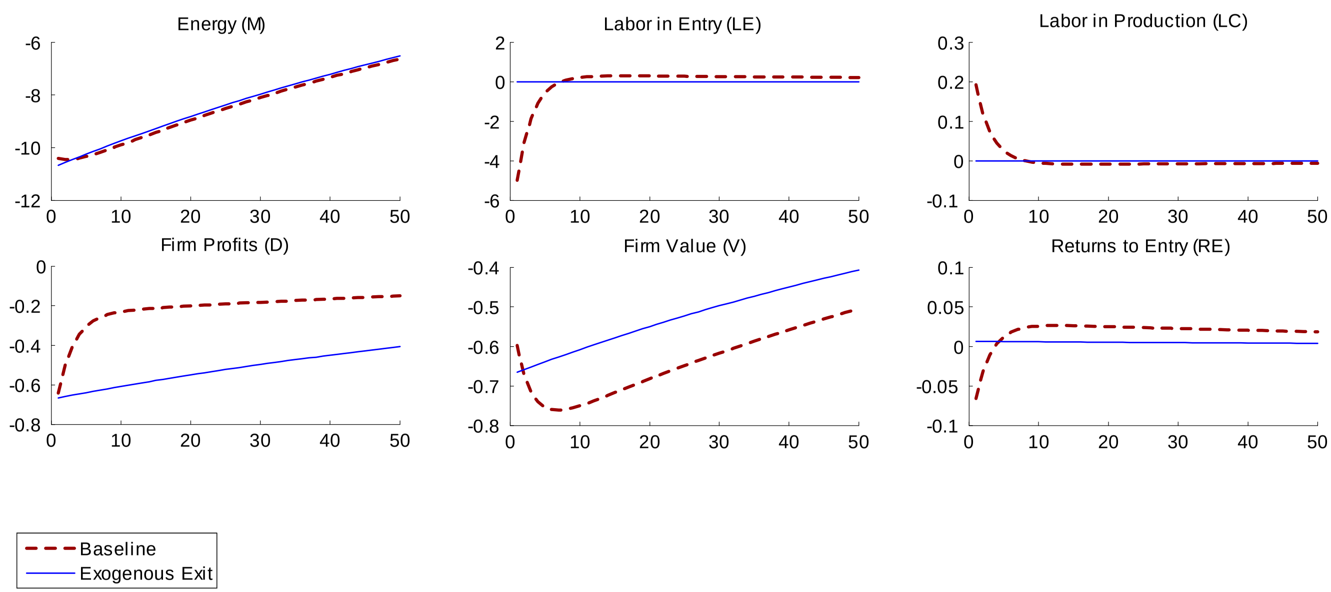
Notes: See notes to Figure 5. Shaded lines represent the impulse responses from the baseline model while solid lines respresent the energy in entry costs model.

Figure 8. 1: Impulse Responses to a 10% pm shock Baseline Model, Exogenous Exit Model



Notes: See notes to Figure 5.

Figure 8. 2: Impulse Responses to a 10% pm shock Baseline Model, Exogenous Exit Model

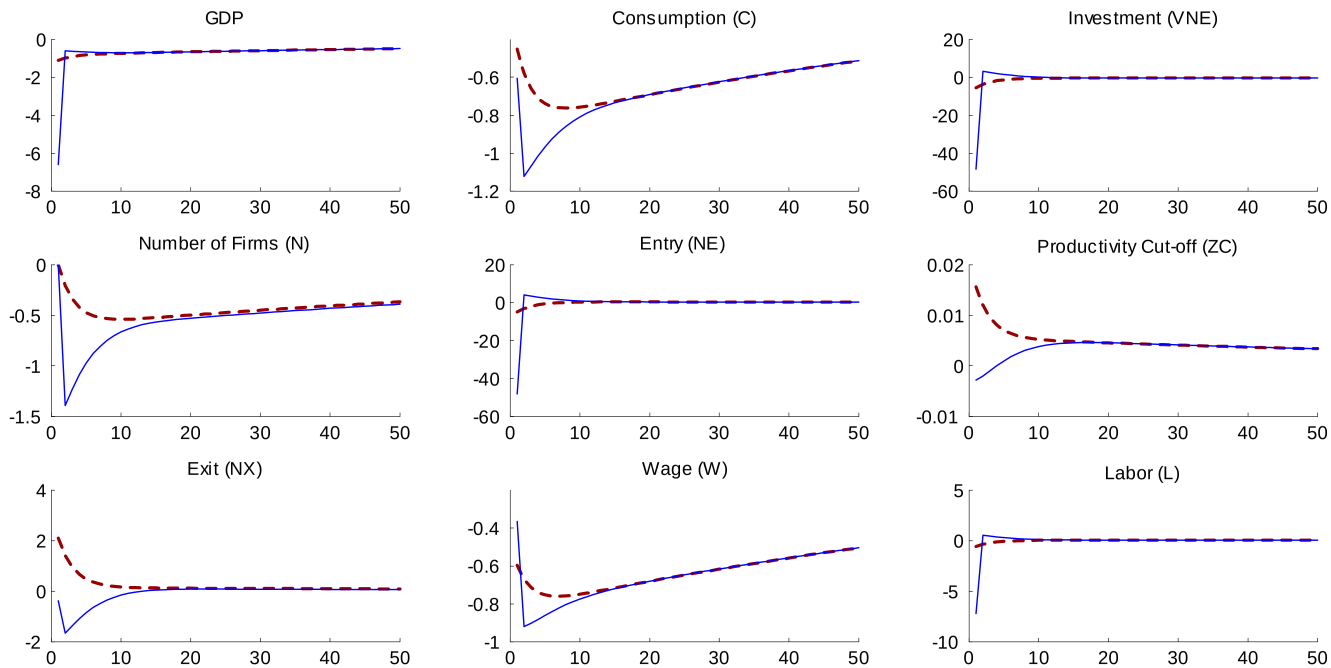


Notes: See notes to Figure 5.

Table 3: Calibrated Parameters (Sticky Price and Wage Model)

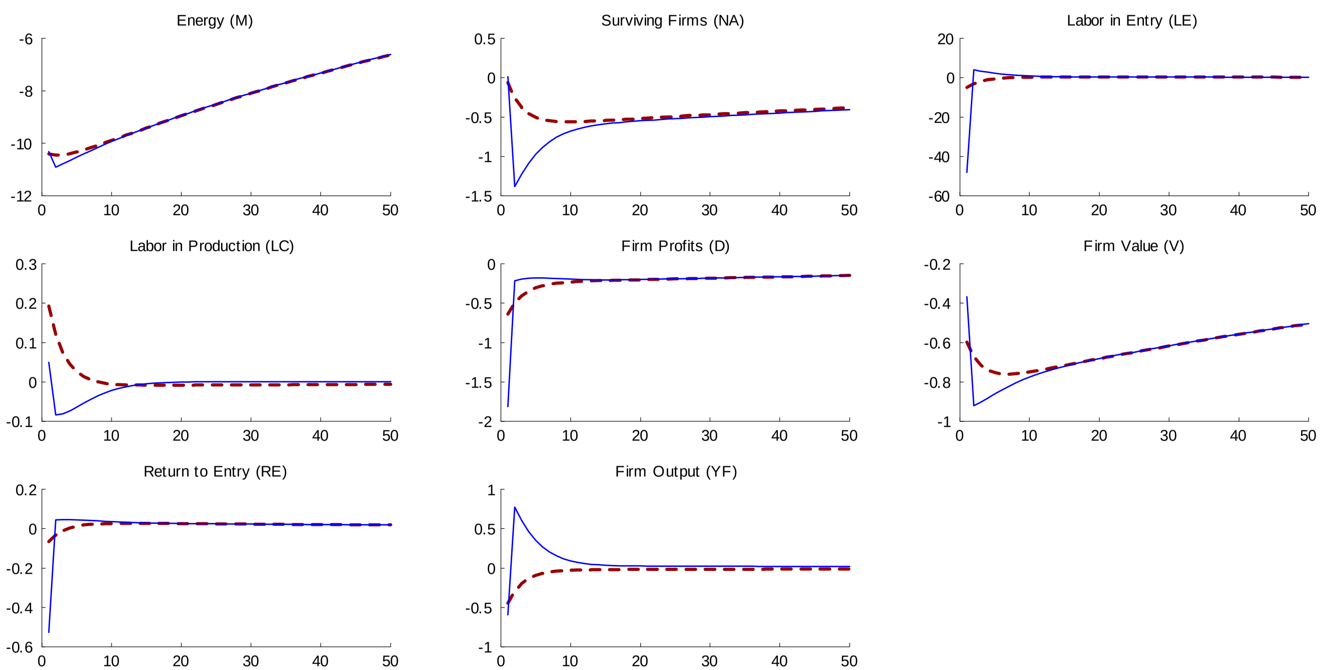
Parameter	Value	Interpretation
β	0.99	Discount factor
θ	3.8	Elasticity of substitution
φ	4	Frisch elasticity
χ	0.924271	Disutility of labor
f_e	1	Entry cost
α	0.9437	Share of labor
δ	0.029	Exit rate in the steady state
Ψ_p	77	Rotemberg Price Stickiness
Ψ_W	10	Rotemberg Wage Stickiness
ε_W	3	Elasticity of substitution for labor
τ_π	1.5*0.2	Interest rate rule coefficient on inflation
τ_I	0.8	Interest rate smoothing
$z_{\min}$	1	Lower bound of Pareto Distribution
κ	4	Shape parameter of Pareto Distribution

Figure 9. 1: Impulse Responses to a 10% pm shock Baseline Model, Sticky Wage Model



Notes: See notes to Figure 5. Shaded lines represent impulse responses in the baseline model while solid lines refer to the sticky wage model.

Figure 9. 2: Impulse Responses to a 10% pm shock Baseline Model, Sticky Wage Model



Notes:See notes to Figure 5. Shaded lines represent the baseline model while solid lines refer to the responses in the sticky wage model

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8 Appendix :

8.1 No Entry Model

Model Summary

1) $\rho_t = \mu_t \lambda_t = \mu_t \frac{bw_t^{\alpha} pm_t^{1-\alpha}}{Z_t}$
2) $d_t = Y_t/N_t[1 - 1/\mu]$
3) $Ct + pm_t M_t = w_t L_t + N_t d_t = Y_t$
4) $w_t = \frac{\alpha}{\mu} \frac{Y_t}{L_t}$
5) $pm_t = \frac{1-\alpha}{\mu} \frac{Y_t}{M_t}$
6) $Y_t = Z_t L_t^{\alpha} M_t^{1-\alpha}$
7) $\rho_t = N_t = 1$
8) $\chi\left(L_t\right)^{\frac{1}{\varphi}} = \frac{w_t}{C_t}$
9) $v_t = \beta(1-\delta) E_t[\frac{C_t}{C_{t+1}}(d_{t+1} + v_{t+1})]$

8.2 Derivation of the Productivity threshold in the Sticky Price, Sticky Wage Model

The zero profit condition that determines the productivity threshold is given below:

$$\sum_{j=1}^{\infty} \beta^j d_{t+j}^* = \sum_{j=1}^{\infty} \beta^j \left[\left(\mu_{t+j}^*(z_t^*) \lambda_{t+j}^p(\widetilde{z}) \frac{\widetilde{z}}{z_t^*} \right)^{1-\theta} Y_{t+j}^c [1 - 1/\mu_{t+j}^*(z_t^*)] - f bw_{t+j}^{\alpha} pm_{t+j}^{1-\alpha} - pac_{t+j}(z_t^*) \right] = 0$$

$$d_{t+j}^* = \mu_{t+j}^*(z_t^*)^{-\theta} \left(\lambda_{t+j}^p(\widetilde{z}) \frac{\widetilde{z}}{z_t^*} \right)^{1-\theta} Y_{t+j}^c [\mu_{t+j}^*(z_t^*) - 1] - X_{t+j} - pac_{t+j}(z_t^*)$$

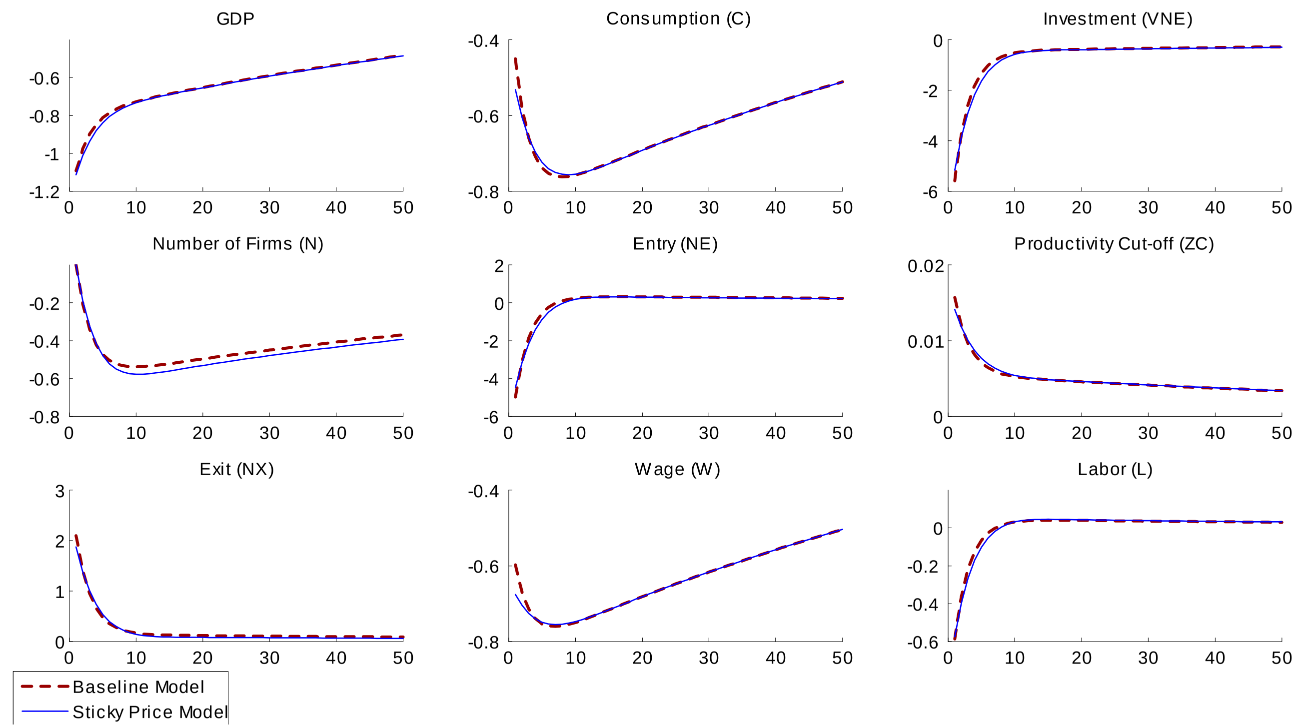
Loglinearising around the steady state;

$$\widehat{d_{t+j}^*} = \left(\frac{\mu^*}{\mu^* - 1} - \theta \right) \widehat{\mu_{t+j}^*} + (1-\theta) \widehat{\lambda_{t+j}^p(z^*)} - \widehat{X_{t+j}},$$

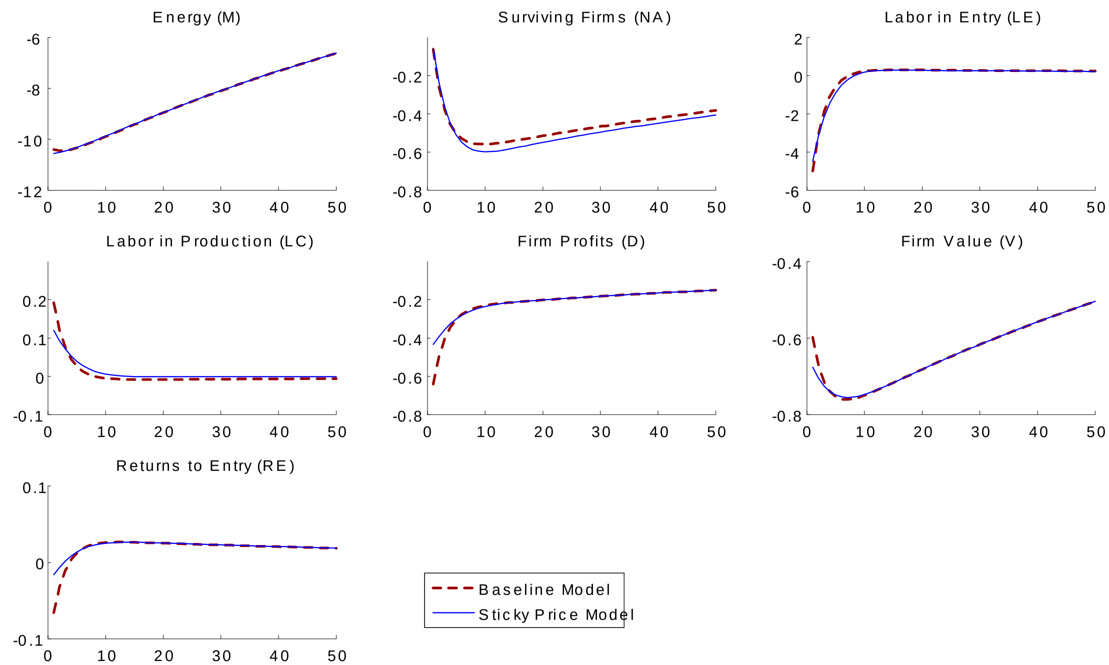
since prices are constant in the steady state, the adjustment costs are zero for the firm with threshold productivity level.

Also since in the steady state $\mu^* = \mu = \frac{\theta}{\theta-1}$, the first term also drops out. So our cut-off productivity equation remains the same as in the baseline model when considering deviations from the steady state.

Impulse Responses from a 10% Energy Price Shock, Baseline Model, Sticky Price Model



Impulse Responses from a 10% Energy Price Shock, Baseline Model, Sticky Price Model



Impulse Responses from a 10% Energy Price Shock: Comparison of Models with and without the Extensive Margin and Sticky Wages