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Abstract

During economic expansions the net product creation and average product quality increase as firms introduce new products with higher quality. The introduction of new products with higher quality produces a quality bias in price level measures. In this paper I develop a firm-entry model with endogenous quality of consumer goods. Following a TFP shock, the price level increases not only due to a larger number of varieties but also due to a higher average quality. Simultaneously, the channel of endogenous quality acts as a propagation mechanism to other variables in the economy, amplifying their response to shocks. This channel can also be either contractionary or shut down, depending on how consumers derive utility from quality.

Keywords: Firm-entry, business cycle, quality, prices.

JEL codes: E32, E20, L11

1 Introduction

Empirical evidence suggests that net product creation is linked to improvements in the quality of goods and heavily procyclical, as replacement of outdated goods by new ones is accelerated during booms - Broda and Weinstein (2010). Furthermore, net product creation is mainly determined by firm entry rather than firm exit. Simultaneously, an extensive literature has been produced on general equilibrium models with endogenous firm entry[1], capable of explaining the dynamics of product creation. However, these models do not account for the dynamics in quality and its role as propagation mechanism to the rest of economy, mainly markups and prices[2].

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[1] Jaimovich and Floetotto (2008), Colciago and Etro (2010) and Bilbiie et al. (2012) are the main examples of these type of models.

[2] Two exceptions are the models in Schmitt-Grohé and Uribe (2012) and Jaimovich et al. (2019). Schmitt-Grohé and Uribe (2012) develop a model with exogenously-determined quality and analyze the importance of quality bias in the setting of inflation targets. Jaimovich et al. (2019) study the trading down in consumption during recessions using a general equilibrium model with endogenous quality.

In this study, I address this shortcoming by introducing endogenous quality into an otherwise standard endogenous firm-entry model. Following a productivity shock, the model generates a positive response of firm creation and average quality level, leading to an increase in the price level. This is consistent, not only with the empirical evidence for net product creation, but also with the findings in Bils (2009) and Broda and Weinstein (2010) of the role of quality improvements in price level dynamics.

In these studies, the authors find that quality improvements account for a significant part of inflation and since statistical authorities do not adjust fully the impact of quality in prices, the inflation rate is consistently overestimated (i.e. quality bias). Likewise as price level is partially determined by quality in the model, the changes in the unadjusted price level are significantly higher than when one accounts for the quality bias.

Since the framework is the standard firm-entry model, the model with endogenous quality maintains its features, such as the procyclical behavior of firm entry and countercyclical response of markups. However, with endogenous quality the model adds one more propagation channel to productivity shocks and the response of the main variables is amplified. Prices and markups, as well as consumption and output, are now determined by the interaction between the number of firms (varieties) and average quality level.

The effect on other variables crucially depends on marginal utility of quality to consumers. When the marginal utility is constant, the channel of transmission of changes in quality to the rest of the economy is broken and the model produces the same results as in Hamano and Zanetti (2018). In that case, the markup is only endogenously determined by the number of firms in the economy that in turn is unaffected by the changes in quality. Therefore, with this specification, changes in quality of goods only have a direct impact (in the same proportion) on prices and profits.

When the marginal utility is increasing, the average quality level is both negatively determined and has a negative effect on the other variables in the economy such as labor, investment and output. Following a productivity shock, as it becomes cheaper to produce consumer goods, the investment in quality by firms decreases. The negative response of quality produces a positive feedback effect on economy and amplifying the responses of output, labor and investment.

In contrast, when there is decreasing marginal utility, a positive exogenous shock in the quality of goods produced leads to a positive response of the consumption, output, labor, markup, firm entry, and prices. Since a TFP shock has a positive effect on quality, the response is amplified by the positive feedback loop generated within the model. Therefore, the model produces a larger response of consumption and prices than in the firm-entry model without endogenous quality.

Since there is no benchmark value to the parameter regulating the marginal utility of quality, I apply the IRF-matching method to the model, in order to find the value of the parameter most consistent with US data. I find that the value of parameter that guarantees the impulse-response functions (IRFs) for the model closest to the ones obtained for the estimated vector autoregression (VAR) is the one implying decreasing marginal utility. This value is consistent with the hypothesis considered in the main case.

In the benchmark specification of the model, It is assumed that quality enters firms' decisions in the same form as intermediate inputs or labor – in each period, quality incorporated in consumer goods is equal to that acquired by firms. This specification is similar to the one used in Jaimovich et al. (2019), where the authors study the food and drinks service industries.

However, for manufactured goods, the quality of the product does not depend only on the quality of the inputs. Rather, it depends on the design, technology and innovation which do not disappear with the manufacturing process, but can become obsolete and require frequent updates. This is translated into the model by considering the quality as stock, like physical capital. Under the new specification the effect of quality on other variables is mitigated, as it fluctuates less as a stock. As a result, the model produces IRFs and second moments closer to the standard firm-entry model.

The remainder of the paper is organized in three sections. In section 2 I present the firm-entry model and discuss the results obtained under different specifications. Section 3 presents an alternative specification of quality incorporation at firm level. Section 4 concludes.

2 Model

2.1 Households

Consider a representative household that derives utility from consumption a_t and disutility from supplying labor l_t. Its objective is to maximize expected discounted utility given by

$$E_o \sum_{t=0}^{\infty} \beta^t U(a_t, l_t), \tag{1}$$

where a_t is the composite consumption index given by

$$a_t = \left[\sum_{i=1}^{N} \left(c_{i,t}(x_{i,t}^{\theta}) \right)^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{2}$$

where c_t and x_t are the quantity and the quality of each variety consumed, respectively, $\varepsilon > 1$ is the elasticity of substitution between varieties and θ is the elasticity of quality in the consumption aggregator. The consumer have the following budget constraint:

$$v_t(N_t + N_t^E)s_{t+1} + a_t Q_t = (\pi_t + v_t)N_t s_t + w_t l_t, \tag{3}$$

where v is the value of each firm, π represents the individual firm's profits, N is the number of firms, N^E stands for the number of newly-created firms, s the share of equity detained by the household and q is the price of consumer goods adjusted by quality.

The first-order condition for the maximization problem are:

$$-\frac{U_{l,t}}{U_{a,t}}=\frac{w_t}{Q_t}, \tag{4}$$

$$v_t=\beta E_t\left[\frac{U_{a,t+1}}{U_{a,t}}\frac{Q_t}{Q_{t+1}}(v_{t+1}+\pi_{t+1})\right], \tag{5}$$

where 4 is the Frisch labor supply and 5 is the Euler equation for share holdings.

For any given level of consumption c_t, the demand of each differentiated variety of goods $i=1,\ldots,N$ in period t must solve the dual problem of minimizing total expenditures $\sum_{i=1}^{N}p_{i,t}c_{i,t}$, subject to the aggregation constraint in 2. The optimal level of demand $c_{i,t}$ for $i=1,\ldots,N$ is given by

$$c_{i,t}=\left(\frac{Q_{i,t}}{Q_t}\right)^{-\varepsilon}a_t x_{i,t}^{\varepsilon(\theta-1)-\theta}, \tag{6}$$

with the nominal quality-adjusted price index, Q_t, defined as

$$Q_t=\left[\sum_{i=1}^{N}\left(q_{i,t}\right)^{1-\varepsilon}di\right]^{\frac{1}{1-\varepsilon}}, \tag{7}$$

$$q_{i,t}=\frac{p_{i,t}}{x_{i,t}}. \tag{8}$$

2.2 Market Structure

In each period, representative household allocate its expenditure EXP_t across varieties according to the demand equation in 6 that can be rewritten as

$$c_{i,t}=\left(\frac{Q_{i,t}}{Q_t}\right)^{-\varepsilon}EXP_t x_t^{\theta-1}x_{i,t}^{\varepsilon(\theta-1)-\alpha}, \tag{9}$$

where $EXP_t=\sum_{i=1}^{N}p_{i,t}c_{i,t}=c_tP_t=a_tQ_tx_t^{1-\theta}$. The inverse demand function is then given by

$$p_{i,t}=\frac{c_{i,t}^{-\frac{1}{\varepsilon}}EXP_t}{\sum_{i=1}^{N}(x_{i,t}c_{i,t})^{\frac{\varepsilon-1}{\varepsilon}}}x_t^{\frac{\alpha-1}{\varepsilon}}x_{i,t}^{\theta-\theta/\varepsilon}. \tag{10}$$

In each period, the firms seeks to maximize its profits by choosing the quantities of consumer goods to produce as the strategic variables[3]:

$$\pi_{i,t}(c_{i,t})=\left[p_{i,t}-\lambda_{i,t}\right]c_{i,t}-p_t^x x_{i,t}, \tag{11}$$

[3] It is assumed that firm compete over quantities (Cournot) since it leads to a price schedule depending on ε and N. This happens because quality (x) is multiplicative in the demand function. Nevertheless, the results for Cournot competition are fairly similar to the obtained with Bertrand - see Etro and Colciago (2010).

where $\lambda_{i,t}$ is the marginal cost and p_t^x is the price of intermediate quality goods. In our model, the intermediate quality goods are produced in a separated sector and acquired by firms producing consumer goods to boost the quality of their products. The demand for quality goods by the producing firms is determined by the effect of $x_{i,t}$ in demand for their consumer goods $c_{i,t}$. By substituting equation 10 in 11 and maximizing profits in order of $c_{i,t}$ we obtain

$$\frac{\varepsilon-1}{\varepsilon} EXP_t x_t^{\frac{\theta-1}{\varepsilon}} x_{i,t}^{\theta-\frac{\theta}{\varepsilon}} \left(\frac{c_{i,t}^{-\frac{1}{\varepsilon}}}{\sum_{i=1}^{N} (x_{i,t}c_{i,t})^{\frac{\varepsilon-1}{\varepsilon}}} - \frac{c_{i,t}^{-\frac{\varepsilon-1}{\varepsilon}} x_{i,t}}{\sum_{i=1}^{N} (x_{i,t}c_{i,t})^{\frac{2\varepsilon-1}{\varepsilon}}} \right) = \lambda_t. \tag{12}$$

By imposing the symmetry in the Cournot equilibrium we obtain the optimal output of each firm:

$$c_t = \frac{\varepsilon-1}{\varepsilon} \frac{N_t - 1}{N_t^2} \frac{EXP_t}{\lambda_t} x_t^{\theta-1}. \tag{13}$$

Substituting the quantities obtained in the inverse price $p_t = \frac{EXP_t}{c_t N_t}$ we obtain:

$$p_t = \mu_t \lambda_t, \tag{14}$$

where the price markup, μ_t, depends endogenously on N_t and x_t and it is defined as:

$$\mu_t(\varepsilon, N_t, x_t) = \frac{\varepsilon}{\varepsilon-1} \frac{N_t}{N_t-1} x_t^{1-\theta}. \tag{15}$$

As they choose quantities, firms also choose the level of quality that maximizes their profits. From the first-order condition we obtain:

$$p_t^x = c_t x_t^{\theta-2} \frac{N_t \theta(\varepsilon-1) - \varepsilon - \theta}{N_t \varepsilon}. \tag{16}$$

In the symmetric equilibrium, $Q_t = q_t N_t^{\frac{1}{1-\varepsilon}}$ so that the variety effect is given by

$$q_t = N_t^{\frac{1}{\varepsilon-1}}. \tag{17}$$

2.3 Firms

In this model it is assumed that the production of each variety of consumer goods only requires labor input $l_{i,t}^c$ and is given by

$$c_{i,t} = p_t z_t l_{i,t}^c, \tag{18}$$

where z_t is the aggregate technology, which follows a first-order autoregressive process:

$$\ln(z_t) = \rho_z \ln(z_{t-1}) + u_t^z, \tag{19}$$

where $u_t^z \sim N(0, \sigma_z)$ is the exogenous innovation in technology. This gives us the marginal cost $\lambda_t = \frac{w_t}{z_t}$. The profits of each firm are given by

$$\pi_t = (1 - \frac{1}{\mu_t})\frac{c_t}{N_t}. \tag{20}$$

As in most of firm-entry models, the number of firms is governed by the law of motion

$$N_{t+1} = (1 - \delta)(N_t + N_t^E), \tag{21}$$

where the $\delta \in [1, 0]$ is the exit rate of firms. The creation of new firms is given by

$$N_t^E = \frac{z_t l_t^e}{\phi^e}, \tag{22}$$

where l_t^e is the labor allocated to firm creation and where ϕ^e is the fixed cost of entering the market. Firms will enter the market until the marginal cost of creating a new firm equals the value of the firm. Therefore, the firm-entry condition is given by

$$v_t = \phi^e \frac{w_t}{z_t} \tag{23}$$

with $\frac{w_t}{A_t}$ defined as the marginal cost of creating new firms.

The market in quality sector operates under perfect competition, meaning that the price paid by firms in the consumer goods sector is the same to what would cost if they produced it themselves. The production function of quality goods is given by

$$x_{i,t} = i_t l_{i,t}^x, \tag{24}$$

where $l_{i,t}^x$ is the labor input in the production of quality goods and i_t is the aggregate technology, which follows a first-order autoregressive process:

$$\ln(u_t) = \rho_u \ln(u_{t-1}) + u_t^i, \tag{25}$$

where $u_t^i \sim N(0, \sigma_i)$ is the exogenous innovation in technology. The price schedule of quality goods is given by

$$p_t^x = \frac{w_t}{i_t}. \tag{26}$$

The model is closed by imposing the labor market clearing condition:

$$l_t = l_t^c + l_t^e + l_t^x. \tag{27}$$

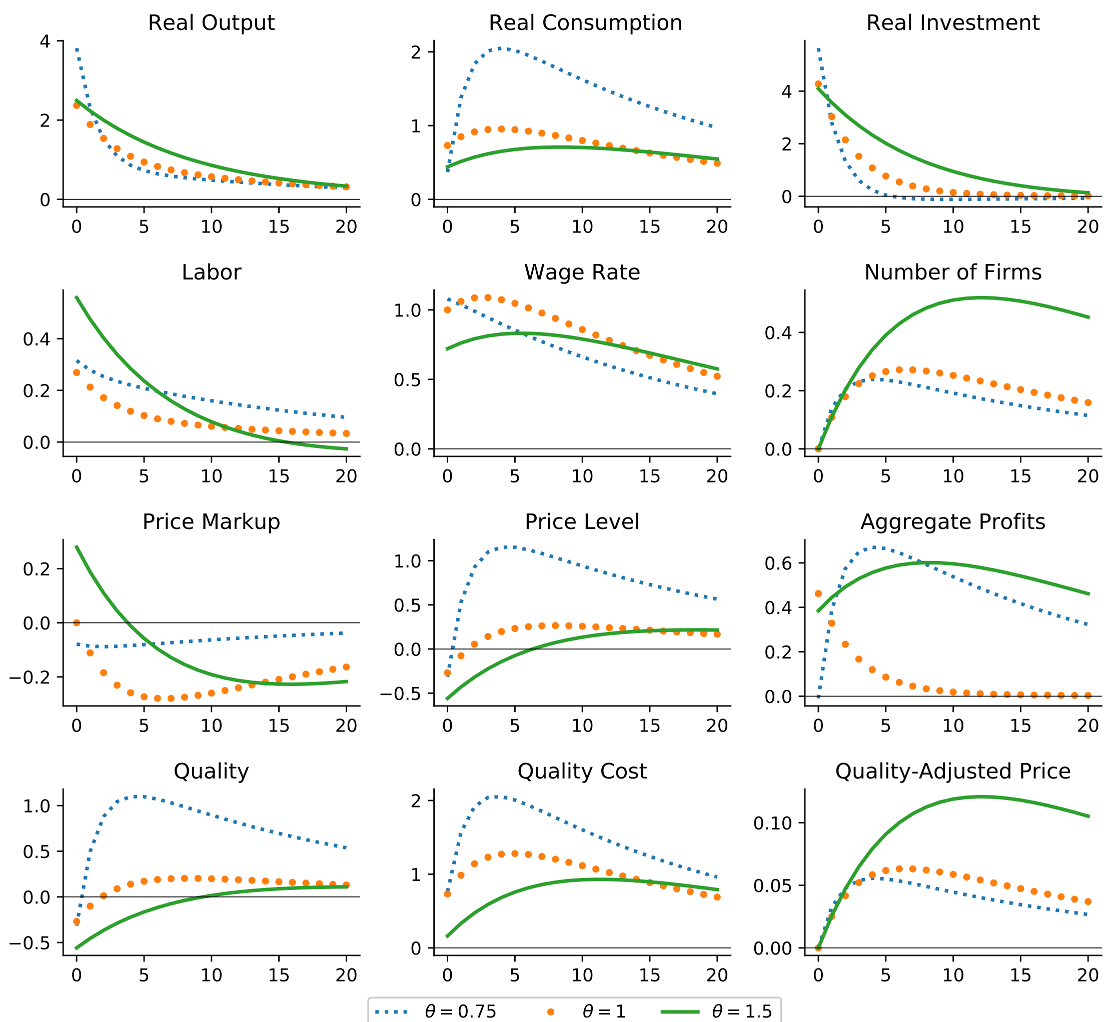
2.4 Calibration and results

For this model, I use the following utility functional form

$$U(a_t, l_t) = \frac{a_t^{1-\sigma} - 1}{1 - \sigma} - \psi \frac{l_t^{1+\chi}}{1 + \chi},$$

where χ and σ are equal to 1, and the parameter ν is positive and calibrated so, in steady-state, the labor supply is equal to 1. Since my model is build over the framework of Bilbiie et al. (2012), I follow their calibration. The discount factor β is set to 0.99, while the exit rate of firms, δ is set to 0.0253. In our calibration, the elasticity of substitution between varieties is higher than in Bilbiie et al. (2012) and equal to $\varepsilon = 5.3$. The fixed cost of entry ϕ^E is equal to 1. The persistence parameters of productivity and preference shocks are set to 0.95. The model is solved by first-order perturbation method.

Figure 1: Impulse-response functions to a one percent productivity shock in the firm-entry model with $\theta = 0.75$, 1 and 1.5



In our model, as in Bilbiie et al. (2012), consumption, output, investment and the wage rate are measured in nominal terms. To obtain these variables in real terms, one has simply to divide them by p_t. In Bilbiie et al. (2012), real consumption is given by c_t/p_t, real wage by w_t/p_t and real investment, since there is no physical capital, is equal to the total value of new firms created and thus given by $ne_t v_t/p_t$. Here, I have to go further than Bilbiie et al. (2012) and I have thus to add the impact of quality in the real output which is given by $y_t = c_t x_t/p_t + ne_t v_t/p_t$.

Figure 1 displays the IRFs to productivity a one percent shock for three different scenarios of endogenous quality. First we have the scenario where the elasticity of quality is lower than one ($\theta = 0.75$), i.e. quality has decreasing marginal utility. In the second scenario, quality exhibits constant marginal utility ($\theta = 1$). Finally, in the third, the elasticity is higher than one ($\theta = 1.5$), i.e. increasing marginal utility over quality.

For the main macro variables such as the output, consumption, investment (measure by $ne_t v_t/p_t$), labor and wage rate, the IRFs from the model are similar, regardless of the value of θ one chooses. On the other hand, the variables related to prices, quality and competition behave differently across the parameter values.

When we consider $\theta = 1$, the price markup is only determined by the number of firms. As new firms enter the market, the markup decreases and the variety effect, measured by the relative price, increases. The consumer substitutes quality (x) for quantity (c), which is now relatively cheaper. As a result, the aggregate profits have an initial positive response, as firms spend less in quality goods. Since the price level has a more positive evolution than quality, the adjusted price, measured by p/x, increases.

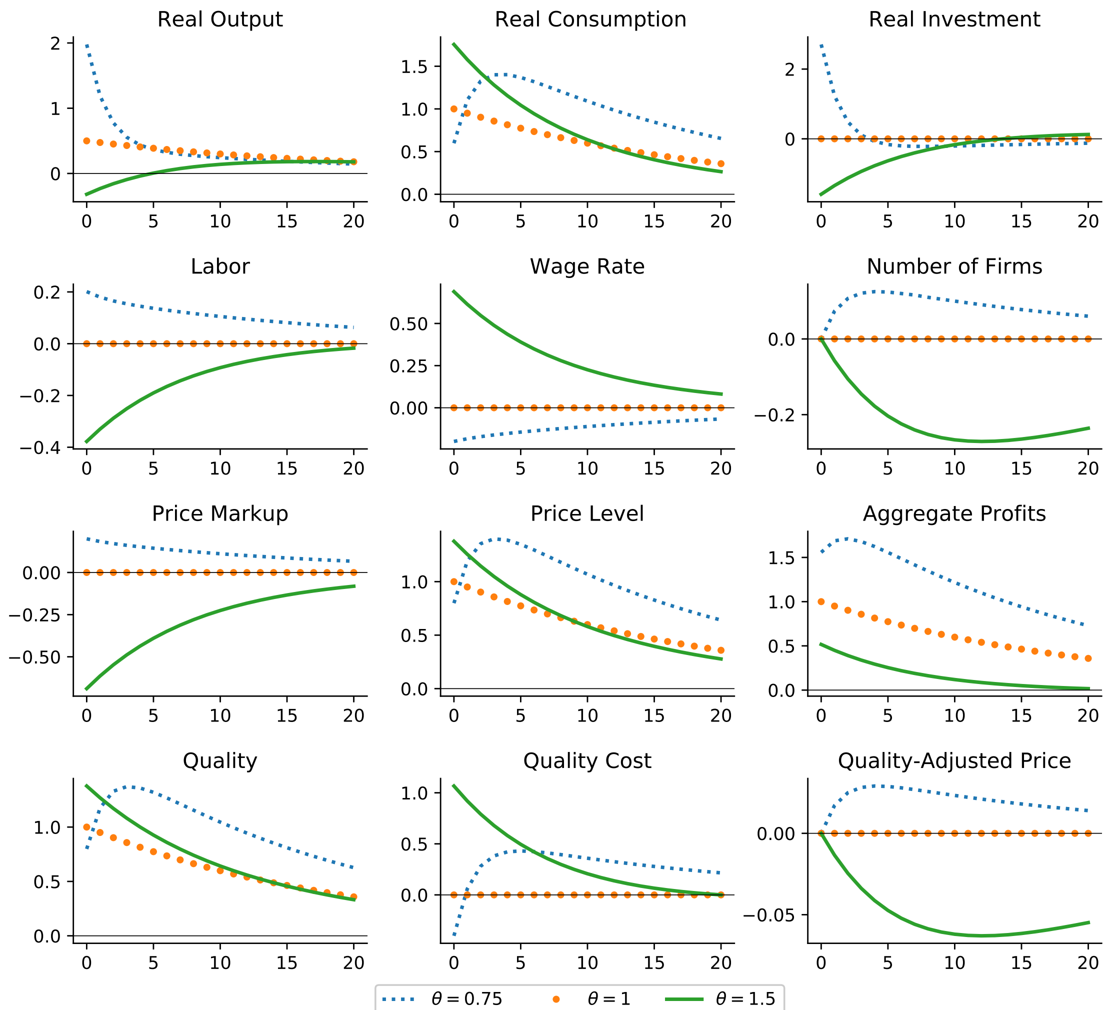
For $\theta > 1$, the decrease in quality as a result of the increase in consumption is more pronounced. Therefore, the price markup displays an initial positive response due to the decrease in quality offsets the negative impact of firm entry. The profits are higher since firms spend even less in quality goods and the number of firms increases more as the value of firms is higher due to higher profits.

In contrast, when we consider $\theta < 1$, the model produces a comovement between consumption and quality. Due to the positive effect of quality, the markup responds less negatively than in the firm-entry-only case.

Nevertheless, the most important result is the two distinct responses of the price levels - unadjusted and quality-adjusted. As the firms react to the TFP shock by increasing the quality incorporated in their products, the (unadjusted) price level increases with it. In fact, this effect accounts for almost the entire variation in price level as shown by small response of the quality-adjusted price level (0.05% at its peak compared to 1% peak in raw price level).

Alternatively, we can consider a TFP shock in quality goods (Figure 2).

Figure 2: Impulse-response functions to a one percent quality shock in the firm-entry model with $\theta = 0.75$, 1 and 1.5

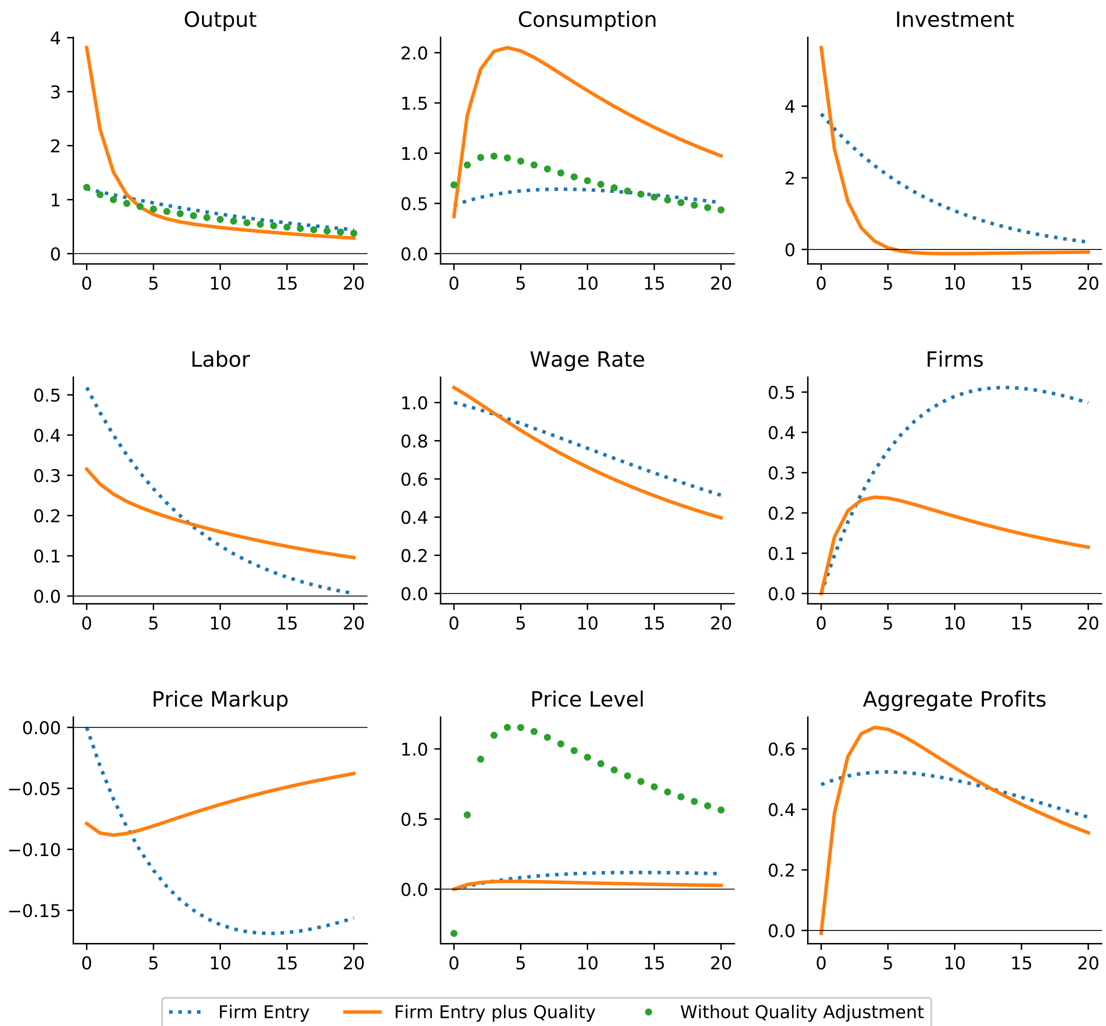


For $\theta = 1$, the response of the variables in consumer goods sector to a quality shock is null. Investment, labor, firm entry, wage rate, and price markup remain constant as the $\theta = 1$ cancels the transmission mechanism to this part of the economy. Real consumption, profits, and price level increase in direct proportion to the increment in quality. As a result, the quality-adjusted price remains unchanged.

On other hand, for $\theta > 1$, the increase in quality has a recessionary effect on the economy, leading to a decrease in firm creation and, by definition, in investment. Due to a reduction in firm creation, the aggregate demand for labor also decreases. The increase in real wage rate is determined by the joint effect of the decrease in the markup and the increase in labor productivity in the quality sector.

As it can be seen in Figures 1 and 2, the model calibrated with decreasing marginal utility in quality consumption produces the IRFs most consistent with empirical evidence. In Figure 3, I compare the model with decreasing marginal utility on quality and the model without endogenous quality.

Figure 3: Impulse-response functions to a one percent TFP shock in firm-entry model with and without endogenous quality



In comparison with the firm-entry model, the model with endogenous quality is able to produce a larger and hump-shaped response in consumption, even when one does not adjust real consumption by the increase in quality (c_t/p_t). However, the response of investment is weaker than the one observed in firm-entry-only model, leading to a lower response of aggregate output.

When the effect quality on price level is removed, the response of the price level is smaller (solid line) and closer to the one obtained for from firm-entry-only (blue doted). Additionally, the IRF of real consumption, adjusted by the improvement in quality, is amplified, leading to a greater response of aggregate output. This is consistent with the findings from Broda and Weinstein (2010), which state that, with a correction of the quality bias present in the deflators, the variance observed in the data for the real variables would be larger. The response of investment is very similar in both cases since the p_t is not very large in any of the models.

2.5 IRF-matching and second moments

In Figure 3 I assumed that the marginal utility from quality goods specified in the consumption aggregator is decreasing and $\theta = 0.75$. However, up to this point we do not know what is the true value of this parameter.To accomplish this, we resort to the methodology presented in Hall et al. (2012).

I consider a recursive VAR $\mathbf{x}_t^{tfp} \equiv [TFP_t \quad HOURS_t \quad GDP_t \quad PCE_t \quad \mu_t \quad \Pi_t]$, where TFP_t is total-factor productivity, $HOURS_t$ is the indicator for total working hours in non-farm business, GDP_t the real Gross Domestic Product, PCE_t the real personal consumption expenditure, μ_t is the average price markup and Π_t are the corporate profits[4]. I use quarterly data for the period 1960:I to 2017:IV. In the VAR estimation I use four lags[5], one constant, one trend, and all variables are in logarithms. Having the impulse-response functions IR^e for the VAR, I denote a vector of parameters $\mathbf{\Theta} = [\rho, \theta]$ and compute the impulse-response functions $IR^m(\mathbf{\Theta})$ for the model. The estimated parameter vector $\hat{\mathbf{\Theta}}$ is the one that minimizes the distance between IR^e and $IR^m(\mathbf{\Theta})$ according to the following equation

$$\hat{\mathbf{\Theta}} = argmin_{\Theta}[IR^e - IR^m(\mathbf{\Theta})]'\hat{W}[IR^e - IR^m(\mathbf{\Theta})],$$

where $\hat{W}$ is the weighting matrix, corresponding to the inverse of the variance-covariance matrix of IR^e.

The IRF-matching is runned on the firm-entry model with endogenous quality and I estimate the values for θ and ρ. From the IRF-matching between the VAR and the firm-entry model, I estimated the value of θ to be equal 0.869, while ρ is equal to 0.916. This results, allows us to focus onwards on the results obtained for case where $\theta < 1$.

Figure 4 presents the response of both the estimated VAR and the theoretical calibrated model. We can observe that the response of real consumption[6] from the model matches almost exactly the response from VAR, while the responses of output and hours match the sign but not the profile. On the other hand, the IRFs from estimated VAR and calibrated model for markup and profits display the same profile but they are less negative in the estimated VAR.

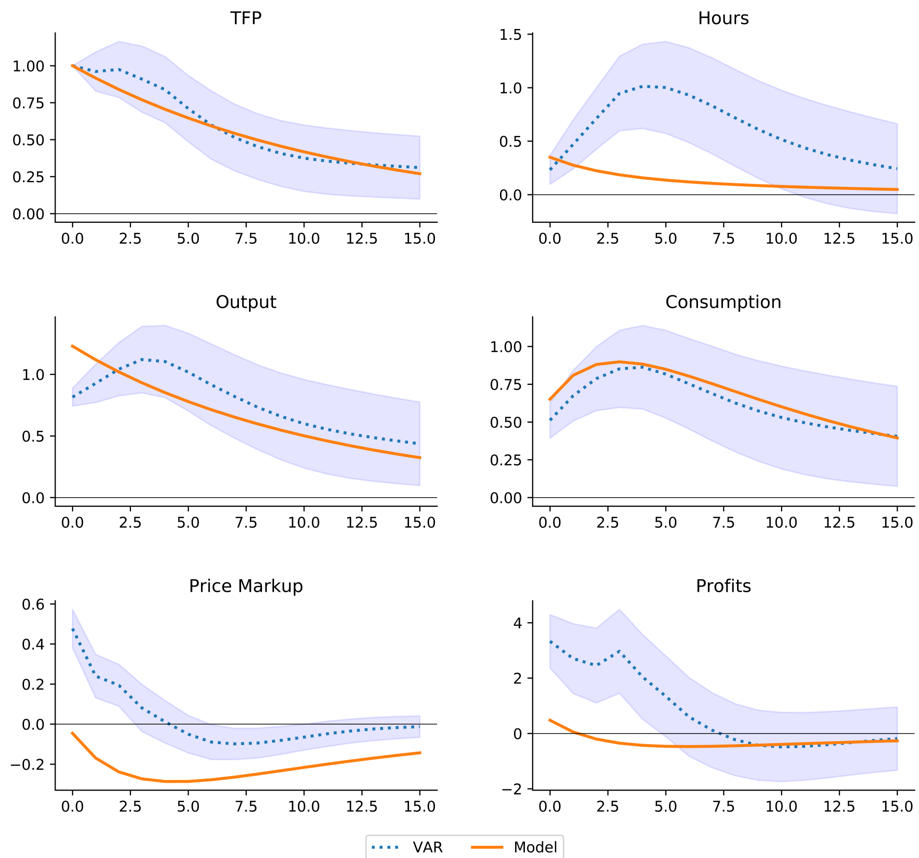
To further assess the fitness of the model to the data, I compare the second moments observed in the US data and the results from the models with and without endogenous quality in Table 1. To allow the comparability with the results obtained by Bilbiie et al. (2012), I define $\chi = 1/4$, $l = 1$, $\rho^a = 0.979$ and variance of u_t^a equal to 0.0072^2. The second moments for variables of consumption, output and investment are calculated in real terms.

[4] The estimation of TFP and the price markup as well as the data sources used in our calculations are presented in Appendix B.

[5] Since I am working with quarterly data, the rule of thumb in the VAR specification is four lags.

[6] As for the second moments, I assume that real consumption and real output in the data do not take fully into account quality changes so I only correct them by using the price level p_t.

Figure 4: Impulse-response functions to a one percent productivity shock for estimated VAR and the calibrated model



As stated previously, to obtain the data-consistent variables in firm-entry models, the real consumption, investment and output need to be corrected by the price level. Up to this point, I corrected even further, by adjusting it also by the quality level. However, since statistical authorities do not take fully into the changes in quality of the products[7] and to increase the comparability with second moments for the firm-entry-only model, the nominal variables are only corrected using the price level p_t.

When observing the standard deviation of the models ($\sigma(X)$), one notices that, besides real consumption and real wage, the model with endogenous quality displays a lower standard deviation. In relative terms ($\sigma(X)/\sigma(Y)$), investment and labor present significantly lower volatility in comparison with the baseline model. In fact, the standard deviation of labor is moment where the model with quality performs worse in comparison with data.

[7]See Broda and Weinstein (2010).

Table 1: Second moments of main macroeconomic variables from US data for 1960:I-2017:IV, firm-entry model and endogenous quality model

	Data				Firm Entry				Firm Entry + Quality			
	$\sigma(X)$	$\frac{\sigma(X)}{\sigma(Y)}$	AC	$r(X,Y)$	$\sigma(X)$	$\frac{\sigma(X)}{\sigma(Y)}$	AC	$r(X,Y)$	$\sigma(X)$	$\frac{\sigma(X)}{\sigma(Y)}$	AC	$r(X,Y)$
Y	1.46	1.00	0.86	1.00	1.54	1.00	0.69	1.00	1.04	1.00	0.68	1.00
C	1.20	0.82	0.87	0.87	0.77	0.50	0.77	0.94	0.99	0.95	0.78	0.99
I	6.59	4.51	0.82	0.90	5.76	3.74	0.66	0.97	3.48	3.35	0.21	0.60
L	1.81	1.24	0.92	0.86	0.90	0.58	0.66	0.97	0.14	0.13	0.47	0.95
W	0.70	0.48	0.92	0.32	0.96	0.62	0.75	0.98	0.99	0.95	0.74	0.99
μ	0.74	0.51	0.55	-0.12	0.06	0.04	0.95	-0.16	0.06	0.06	0.87	-0.73
Π	7.96	5.45	0.80	0.59	0.74	0.48	0.76	0.96	0.55	0.53	0.20	0.56

As for the other macro variables, the presence of endogenous quality allows the model to match the second moments closely observed for consumption and improve the results obtained for both the markup and aggregate profits.

Table A.2 in the appendix presents the second moments for the model with θ equal to 1 and 1.5. As the value of θ increases, the model produces lower standard deviations. For some variables, such as investment, labor and profits, the persistence of shocks, measured by the autocorrelation, also decreases. At the same time, the increase in θ produces a price markup more negatively correlated with the output.

The second moments obtained for the different values of θ suggest that a model with a $\theta < 1$ produces results that are more consistent with the data.

3 Quality as a stock

Up to this point, it was assumed that the quality of each variety of consumption goods was equal to the output of quality sector, meaning that the quality of goods consumed can have significant fluctuation between periods. This can be plausible for services industries - e.g. food services - where quality depends directly on the inputs used, but not so much for consumer goods - e.g. gadgets - where most of the quality depends on technology and design behind the product. In consumer goods, the increase in quality is mostly determined by innovation, where new improvements add to the pre-existing quality.

Here, we consider that the quality of each variety is a stock that evolves according to the following law of motion

$$x_{i,t+1} = (1 - \delta^x)x_{i,t} + inv_{i,t}, \tag{28}$$

where $inv_{i,t}$ is the improvement in x, equal to the output of quality sector, and δ^x is the depreciation rate of

quality. The profits of firms in the consumer goods sector are now given by

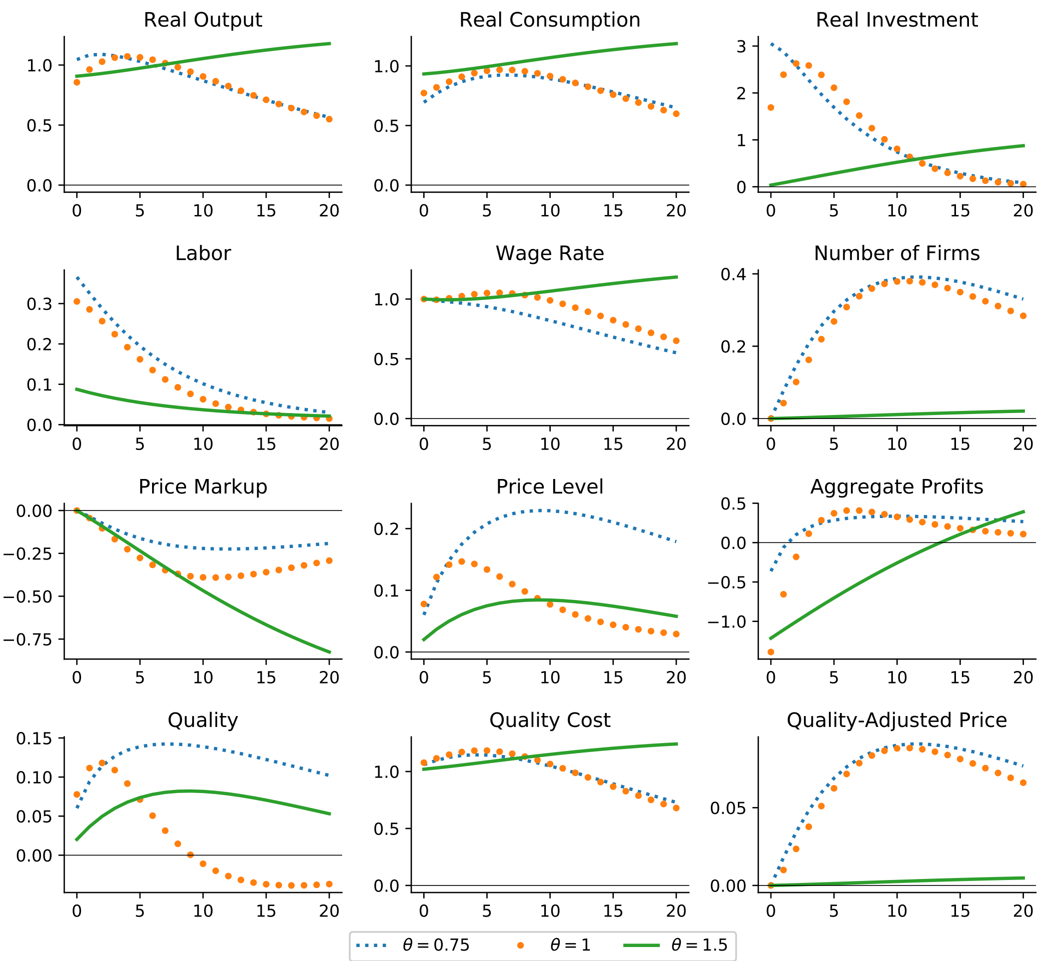
$$\pi_{i,t}(c_{i,t}) = \left[p_{i,t} - \lambda_{i,t}\right] c_{i,t} - p_t^x inv_{i,t}, \tag{29}$$

and the first-order condition for the demand of quality goods is:

$$p_t^x - (1-\delta^x)p_{t+1}^x = c_t x_t^{\theta-2} \frac{N_t \theta(\epsilon - 1) - \epsilon - \theta}{N_t \epsilon}. \tag{30}$$

As there are no reference values for δ^x, I consider a $\delta^x = 0.1$, meaning that a given variety becomes obsolete within 2.5 years. This value of depreciation, that is higher than $\delta = 0.253$ considered for the exit rate of the firms, is low enough to guarantee dynamics different from the main model, while high enough to avoid the low volatility generated by the stock of quality goods. Figure 5 presents the IRFs from the model for different values of θ.

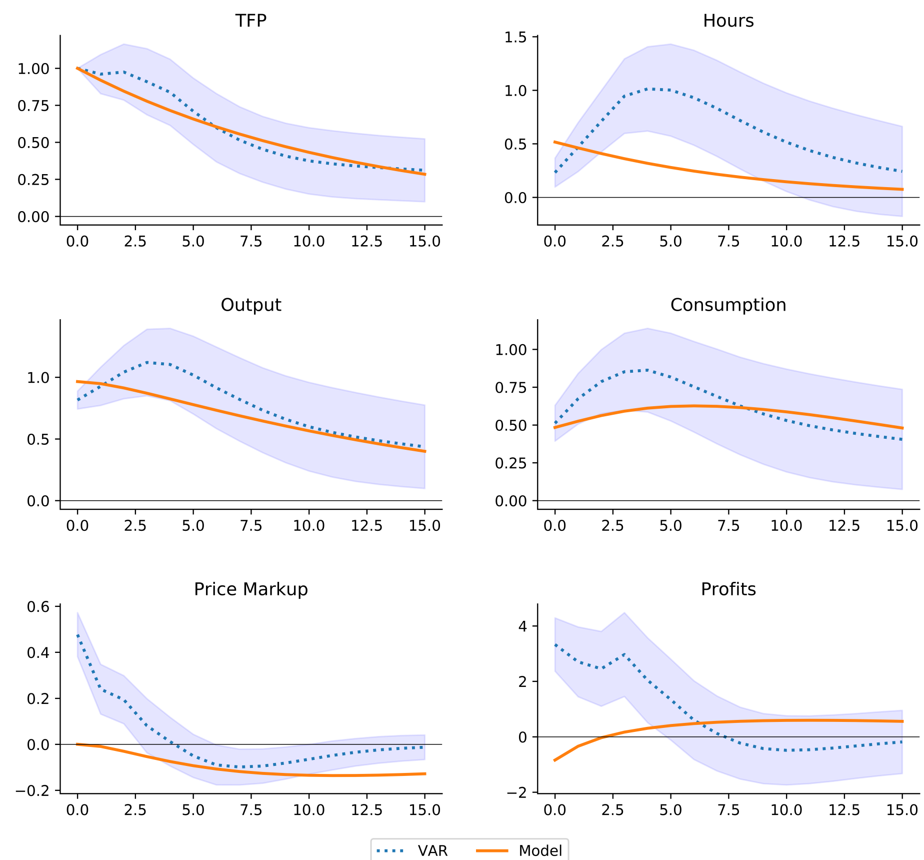
Figure 5: Impulse-response functions to a one percent TFP shock for quality-as-stock model



The impulse responses obtained from the model with stock of quality are similar to the ones from our main model, with the exception for the impulse responses for values of θ higher than one. For these values,

the model generates IRFs of investment, labor and firm entry below the ones observed in our main model. At the same time, the aggregate profits now exhibit a negative response to TFP shocks because quality responds positively leading to lower markup and higher costs. As the markup is lower for a longer period, the real wage response is also more persistent.

Figure 6: Impulse-response functions to a productivity shock for estimated VAR and the calibrated model with quality as a stock



For $\theta < 1$, the only difference is that the response of aggregate profits, which is now positive, determined by a lower cost imposed by the increase in quality. With the new quality specification, the model produces impulse responses that match closely the ones observed for the model with only firm entry - see Figure C.8. Since the quality of goods specified as stock exhibits lower volatility through the business cycle, its effect on other variables is mitigated. As a result, the model with low δ^x generates IRFs closer to the ones for firm-entry-only, while with high δ^x the IRFs are closer to the ones in benchmark model of endogenous quality.

As in the previous section, one can estimate the "true" value of the parameter θ in the model with quality

as a stock using the IRF-matching method. In this case, the value that minimizes the distance of IRFs of the model to the ones from the VAR is 0.646 (and $\rho = 0.92$). The lower value of θ is explained by the relatively lower effect of quality as a stock, which requires values of θ further away from 1. Figure 6 presents the IRFs for the estimated VAR and the calibrated model. In comparison with the results obtained for the benchmark model, presented in Figure 4, the calibrated quality-as-stock model generates IRF of labor closer to the ones obtained for the estimated VAR. However, this result is obtained at the cost of a less accurate IRF of consumption and profits, where the benchmark model performs significantly better. Likewise, second moments of investment and labor obtained for the model with $\theta = 0.75$ are also more in line with the ones generate by US data, while producing variables of consumption and profits less correlated with output. (Table C.4).

4 Conclusion

In recent years, a considerable amount of literature on dynamics of product creation and destruction, as well as its effects on prices, was produced. Simultaneously, the literature on general equilibrium models addressed the dynamics of product creation and destruction through the introduction of endogenous firm entry. In these models prices and markups dynamics through the business cycle are fully determined through the number of varieties (i.e. firms) in the economy. However, as found in Bils (2009) and Broda and Weinstein (2010), quality changes account for a significant part of price dynamics.

To address this gap in general equilibrium models literature, a mechanism of endogenous quality in consumption was introduced in a standard firm-entry model. With endogenous quality, the model is able to replicate the response of product quality and prices observed in data[8], while maintaining all the desirable properties of the firm-entry models.

The way in which quality of each variety is introduced in aggregate consumption allows for its marginal utility to be defined as either decreasing, constant or increasing. As such, the value assumed for the parameter regulating the marginal utility generated by quality determines the effect of quality on the markup, prices, profits, and entry decisions of firms. When the marginal utility obtained from quality of goods consumed is constant ($\theta = 1$), the transmission of quality to other variables is shut down and changes in quality only have an effect on the unadjusted price level (higher quality, higher prices), profits (higher prices, higher profits) and composite consumption (due to higher quality of goods consumed). For increasing marginal utility, positive changes in quality have a negative impact on the economy as firms trade away the quantity produced for the increased quality in their products. The reduction in the quantities of goods consumed leads to a reduction in labor demand, investment, and the markup.

However, when quality is considered to provide decreasing marginal utility ($\theta < 1$)[9], the response of

[8]See Bils (2009) and Broda and Weinstein (2010), as stated above.

[9]This is the case where the model matches best with data – see subsection 2.5.

quality to a TFP shock is positive, leading to a feedback loop that is only partly offset by the response of the average price markup. When compared with the canonical firm-entry model, the introduction of endogenous quality amplifies the IRF for consumption and output, and produces a less negative response for the price markup due to the positive effect of quality. With the inclusion of endogenous quality, the firm entry model improves its second moments for real consumption and aggregate profits.

Moreover, firms in consumer goods markets respond by increasing the quality incorporated in their goods and, with it, the prices charged to consumers. With endogenous quality, the firm-entry model has two different sources of price changes – quality and variety. In fact, this effect of quality accounts most of variation in price level after a TFP shock, which is consistent with the findings in Bils (2009).

Finally, in contrast with the benchmark model, where quality consumed by households is equal to the amount defined by firms every period, I considered an alternative specification where the quality goods can be accumulated by firms through a law of motion similar to the one of capital accumulation[10].

While the definition of quality as a flow is appropriate when one considers the services industries, where the quality crucially depends on the inputs used in each period, the quality-as-stock approach is closer to what is observed in the production of goods, where the quality of each product depends on the investment from firms in R&D and equipment. This type of investment does not disappear with the production of the goods but rather become obsolete over time.

With quality defined as a stock, its effect on the economy is weakened since the volatility of stocks is smaller. Nevertheless, the model holds the same properties and still outperforms the standard firm-entry model.

References

Afonso, A. and Costa, L. F. (2013). Market power and fiscal policy in OECD countries. *Applied Economics*, 45(32):4545–4555.

Bilbiie, F. O., Ghironi, F., and Melitz, M. J. (2012). Endogenous Entry, Product Variety, and Business Cycles. *Journal of Political Economy*, 120(2):304–345.

Bils, M. (2009). Do Higher Prices for New Goods Reflect Quality Growth or Inflation?*. *The Quarterly Journal of Economics*, 124(2):637–675.

Broda, C. and Weinstein, D. E. (2010). Product Creation and Destruction: Evidence and Price Implications. *American Economic Review*, 100(3):691–723.

Colciago, A. and Etro, F. (2010). Real business cycles with Cournot competition and endogenous entry. *Journal of Macroeconomics*, 32(4):1101 – 1117.

Etro, F. and Colciago, A. (2010). Endogenous Market Structures and the Business Cycle. *The Economic Journal*, 120(549):1201–1233.

Hall, A. R., Inoue, A., Nason, J. M., and Rossi, B. (2012). Information criteria for impulse response function matching estimation of DSGE models. *Journal of Econometrics*, 170(2):499 – 518. Thirtieth Anniversary of Generalized Method of Moments.

[10] See section 3.

Hamano, M. and Zanetti, F. (2018). On Quality and Variety Bias in Aggregate Prices. *Journal of Money, Credit and Banking*, 50(6):1343–1363.

Jaimovich, N. and Floetotto, M. (2008). Firm dynamics, markup variations, and the business cycle. *Journal of Monetary Economics*, 55(7):1238 – 1252.

Jaimovich, N., Rebelo, S., and Wong, A. (2019). Trading down and the business cycle. *Journal of Monetary Economics*, 102:96 – 121. Carnegie-Rochester-NYU ConferenceSeries on Public Policy“A Conference Honoring the Contributions ofCharles Plosser to Economics”Held at the University of RochesterSimon Business SchoolApril 20-21, 2018.

Schmitt-Grohé, S. and Uribe, M. (2012). On quality bias and inflation targets. *Journal of Monetary Economics*, 59(4):393 – 400.

A Main Model

Figure A.7: Impulse-response functions to three types of shocks for the main model

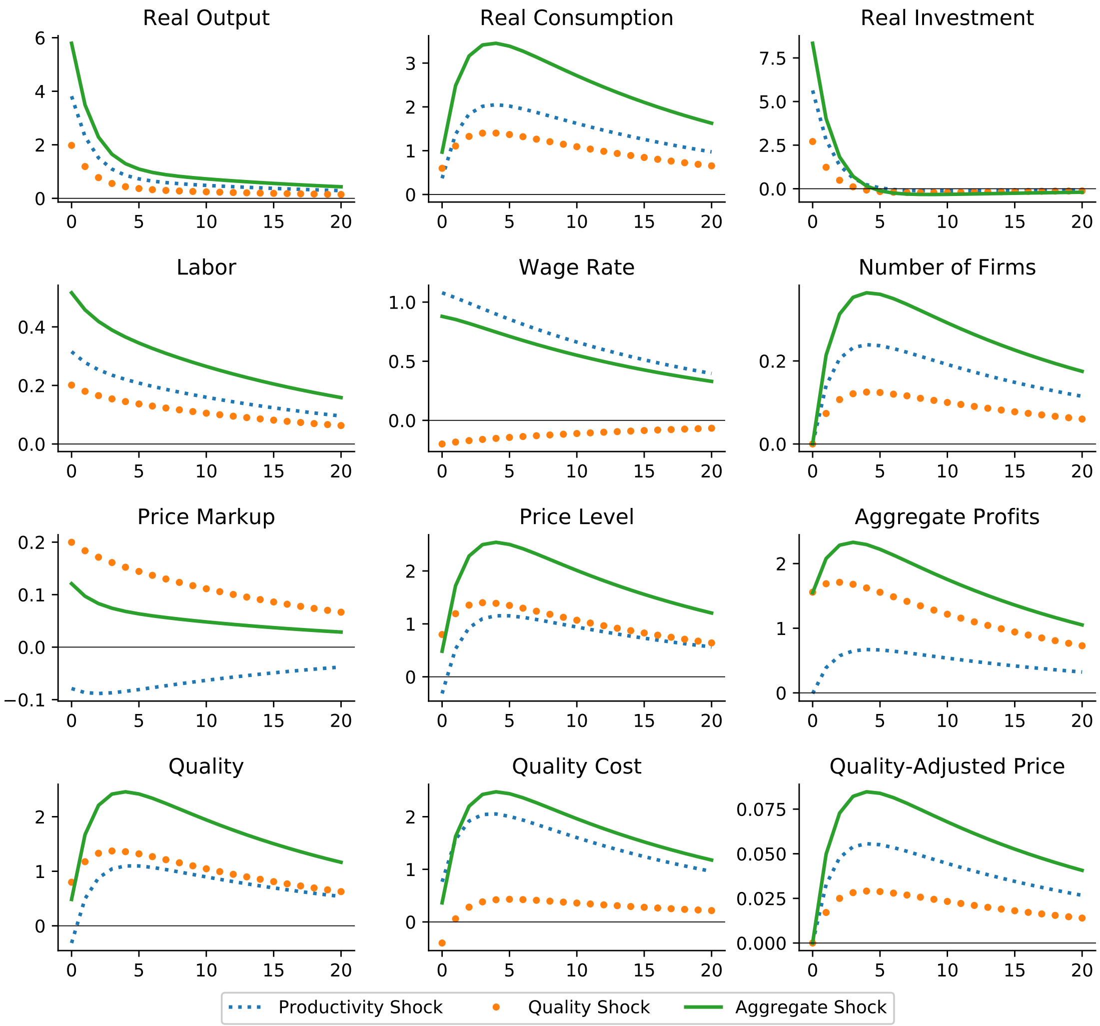


Table A.2: Second moments of main macroeconomic variables from US data for 1960:I-2017:IV, model with $\theta = 1$ and model with $\theta = 1.5$

	Data				$\theta = 1$				$\theta = 1.5$			
	$\sigma(X)$	$\frac{\sigma(X)}{\sigma(Y)}$	AC	$r(X,Y)$	$\sigma(X)$	$\frac{\sigma(X)}{\sigma(Y)}$	AC	$r(X,Y)$	$\sigma(X)$	$\frac{\sigma(X)}{\sigma(Y)}$	AC	$r(X,Y)$
Y	1.46	1.00	0.86	1.00	1.02	1.00	0.69	1.00	1.01	1.00	0.73	1.00
C	1.20	0.82	0.87	0.87	0.99	0.97	0.77	0.99	1.01	1.00	0.77	1.00
I	6.59	4.51	0.82	0.90	2.96	2.90	0.22	0.61	2.10	2.08	0.10	0.52
L	1.81	1.24	0.92	0.86	0.11	0.11	0.33	0.83	0.05	0.05	0.21	0.75
W	0.70	0.48	0.92	0.32	1.01	0.99	0.76	0.99	1.03	1.02	0.78	1.00
μ	0.74	0.51	0.55	-0.12	0.10	0.10	0.84	-0.65	0.14	0.14	0.77	-0.68
Π	7.96	5.45	0.80	0.59	0.70	0.68	0.23	0.41	0.87	0.86	0.14	0.20

B US Data and Markup estimation

As stated in subsection 2.5, I follow Afonso and Costa (2013) in our average markup's estimation. In their paper, the short-run markup is a function of labor share and defined as

$$\mu_t = \frac{1-\alpha_t}{s_t}\frac{1}{1-\phi_t}, \tag{B.31}$$

where s_t is the labor share, α_t is the long-run capital share and ϕ_t is the measure of increasing returns

$$\phi_t = \frac{\mu^* - 1}{\mu^*}\frac{K_t^{*\alpha_t} L_t^{*1-\alpha_t}}{K_t^{\alpha_t} L_t^{1-\alpha_t}}, \tag{B.32}$$

where μ^* is steady-state average markup and $K*_t$ and $L*_t$ are the steady-state level of capital and labor input, respectively. Substituting A.27 into markup equation we obtain

$$\mu_t = \frac{1-\alpha_t}{s_t}\frac{\mu^*}{\mu^* - (\mu^* - 1)x_t}, \tag{B.33}$$

where $x_t = \frac{HP(K_t^{\alpha_t} L_t^{1-\alpha_t})}{K_t^{\alpha_t} L_t^{1-\alpha_t}}$. Both α_t and the long-run values of output are obtained through the Hodrick-Prescott filter. The steady-state markups is same as in Afonso and Costa (2013) and is equal to 1.203.

The TFP series used in the VAR were estimated through the following equation

$$\Delta TFP_t = \Delta(Y_t^h L_t) - \alpha_t K_t - (1-\alpha_t)L_t, \tag{B.34}$$

where $Y_t^h L_t$ is the real output of Nonfarm Business Sector. Table B.3 presents the data sources for the series used in our estimations.

Table B.3: Data sources 1960:I-2017:IV

Variable	Series	Code	Source
Y	Real Gross Domestic Product	GDPC1	FRED
C	Real Personal Consumption Expenditures	PCEC96	FRED
L	Nonfarm Business Sector: Hours of All Persons	HOANBS	FRED
Y^h	Nonfarm Business Sector: Real Output Per Hour of All Persons	OPHNFB	FRED
K	Net Capital Stock	OKND	AMECO
s	Compensation of Employes/Gross Domestic Product	COE/GDP	FRED
W	Nonfarm Business Sector: Real Compensation Per Hour	COMPRNFB	FRED
π	Corporate Profits with IVA and CCAdj	CPROFIT	FRED

C Quality as stock

Table C.4: Second moments of main macroeconomic variables from US data for 1960:I-2017:IV, for firm-entry model and firm-entry with quality as stock

	Data				Firm Entry				Firm Entry + Quality			
	$\sigma(X)$	$\frac{\sigma(X)}{\sigma(Y)}$	AC	$r(X,Y)$	$\sigma(X)$	$\frac{\sigma(X)}{\sigma(Y)}$	AC	$r(X,Y)$	$\sigma(X)$	$\frac{\sigma(X)}{\sigma(Y)}$	AC	$r(X,Y)$
Y	1.46	1.00	0.86	1.00	1.54	1.00	0.69	1.00	1.29	1.00	0.80	1.00
C	1.20	0.82	0.87	0.87	0.77	0.50	0.77	0.94	0.82	0.64	0.76	0.96
I	6.59	4.51	0.82	0.90	5.76	3.74	0.66	0.97	5.40	4.19	0.85	0.95
L	1.81	1.24	0.92	0.86	0.90	0.58	0.66	0.97	0.74	0.57	0.74	0.90
W	0.70	0.48	0.92	0.32	1.00	0.65	0.76	0.95	0.94	0.73	0.73	0.98
μ	0.74	0.51	0.55	-0.12	0.06	0.04	0.95	-0.16	0.10	0.08	0.95	0.11
Π	7.96	5.45	0.80	0.59	0.74	0.48	0.76	0.96	1.64	1.27	0.50	0.06

Figure C.8: Impulse-response functions to a one percent TFP shock for firm-entry model and quality-as-stock model