On Quality and Variety Bias in Aggregate Prices*

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December 2014

Abstract

How do product variety and quality affect the aggregate price bias? We develop a general equilibrium model that accounts for the joint interaction of product quality and variety and find that the aggregate price bias is pro-cyclical and that the contribution of product variety is persistent whereas the contribution of product quality becomes counter-cyclical in the medium to long run. We show that accounting for product quality and variety has critical implications on the measure of cyclical fluctuations. Permanent entry deregulation decreases both components of aggregate price bias.

Keywords: Firm's entry and exit, product quality, product variety

JEL: D24, E23, E32, L11, L60

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1 Introduction

Changes in aggregate prices are bias if they fail to account for variations in prices from shifts to new products or from changes in product quality. Errors in the measurement of price changes have far-reaching effects since indices of price changes are key indicators for policymakers, are used by statisticians to deflate nominal data, and serve as reference statistics for updating financial contracts and wages. An accurate measure of aggregate prices, and hence the true cost of living, is critical for the assessment of fiscal and monetary policy stance and the implementation of public policies. A number of empirical studies document a significant bias in the measure of aggregate price changes due to inaccurate accounting of product quality and variety.[1] Overall, the consensus is that product quality and variety significantly contribute to movement in aggregate prices.

Despite the extensive empirical research on the topic, there are no theoretical studies that formalize the effect of product quality *and* variety on the aggregate price bias. This paper is the first study that develops a simple general equilibrium model that accounts for the joint interaction of product quality and variety and assesses their impact on aggregate prices. The theoretical framework disentangles the contribution of both components to the aggregate price bias and studies their cyclical properties. Variety creation occurs since sunk entry costs limit the number of newly created products, as in Bilbiie et al. (2012), and variety destruction occurs since firms have different capability levels and need to sustain a common operational cost to continue production otherwise exit the market, as in Hamano and Zanetti (2014). Each firm has a specific productivity and manufactures a distinct product of a specific quality. Hence, both product quality and variety are

[1] An early comprehensive study by Boskin et al. (1996) finds that U.S. inflation had upward bias of 1.1 percent per year and more than half of the total bias was attributed to unmeasured quality improvements. More recently, Bils (2009) shows that price increases due to new product variety and changes in quality are an important source of aggregate price bias and inflation is overstated by nearly 2 percentage points per year. Similarly, Broda and Weinstein (2010) document a 0.8 percent annual upward bias in price changes by using a dataset that covers around 40 percent of all expenditures on goods for U.S. households. They also infer that the price bias is pro-cyclical and that official business cycle statistics underestimate the variability of major economic variables.

endogenously determined and interact in the determination of the aggregate price bias. In times of high aggregate demand (i.e. high aggregate productivity), firms with costly technology enter the market and produce high quality goods.[2] As a result, the number of product varieties and the average quality increase, generating a pro-cyclical bias in aggregate prices. Therefore, the aggregate price index displays an upward bias if it does not account for variety and quality changes, as documented by Broda and Weinstein (2010).

Numerical simulations of the model enable us to disentangle the contribution of product quality and variety to the aggregate price bias. In the aftermath of a positive productivity shock, the number of producers that use costly technology and manufacture high quality goods increases, thereby also increasing product quality and variety. Hence, the bias in aggregate prices rises on impact. However, once the positive technology shock vanishes and the economy returns to the equilibrium, firms use efficient technology to produce low quality goods in order to be profitable in the market. Because of the relatively pronounced fall in product quality, the bias of aggregate prices decreases during the transitory dynamics to the equilibrium.

The analysis shows that improperly accounting for product quality and variety in the measure of aggregate prices has critical implications on the measure of cyclical fluctuations. In particular, we show that if the consumption deflator does not account for changes in the product quality and variety, mis-measurement of aggregate fluctuations occur, implying that the variability of major economic variables is underestimated.

We use the model to determine how permanent entry deregulation influences the aggregate price bias through its effect on product quality and variety. Entry costs interact with product quality and variety because they affect the firm's incentives to introduce new products. In the aftermath of permanent deregulation, the number of entrants increases but the total number of producers remains unchanged since endogenous destruction increases. Interestingly, however, we show that a permanent change in deregulation affects

[2]The positive correlation between quality and marginal cost is supported by the empirical results in Verhoogen (2008) and Kugler and Verhoogen (2012).

the composition of the firms in the market, which retains firms with low marginal cost and low quality products.

This paper is related to and builds on two distinct strands of literature. First, it is related to the empirical studies that investigate the impact of product variety and quality on aggregate price bias. In addition to the studies we mentioned in the outset, works by Hausman (2003), Bils (2001), and Broda and Weinstein (2004, 2006, 2007) show that product quality and variety biases are critical for an accurate measurement of aggregate prices. Unlike those studies, our work is mainly theoretical and focuses on disentangling the contribution of product quality and variety and on studying the cyclical properties of the aggregate price bias. In this respect, our paper is also related to Schmitt-Grohe and Uribe (2012), who investigate the effect of quality bias on the optimal inflation target by using a model with staggered price setting. Our study has a different focus and uses a different model, whose main dynamics are based on endogenous product variety and quality and which abstracts from nominal rigidities. **Finally, our work is related to studies that use endogenous growth models enriched with the Schumpeterian idea of creative destruction due to changes in product quality, as described in Aghion and Howitt (1992, 2009). Our model, however, focuses on the effect of changes in variety and entry deregulation on the aggregate price bias. [MASA: Do we need these sentences in bold?].**

Second, the analysis is related to the recent literature on product quality in international trade. Influential studies that use product quality to explain trade patterns across countries are Schott (2004), Verhoogen (2008), Hallak and Schott (2011), Baldwin and Harrigan (2011), Johnson (2012), Feenstra and Romalis (2012) and Manova and Zhang (2012). In our paper, the presence of product quality allows producers with relatively high unit prices to stay in the market due to their lower quality-adjusted prices. The trade literature uses a similar mechanism to explain why firms with high prices and high quality are able to export to foreign markets. However, unlike the trade literature, our paper focuses on a closed economy and investigates the cyclical properties of product quality and their link to aggregate price bias.

The remainder of the paper is as follows. Section 2 presents the model. Section 3 derives the model-consistent bias in aggregate prices. Section 4 presents the results, by showing the cyclical properties of the price bias and assessing the effect of a permanent entry deregulation. Section 5 concludes.

2 The model

The economy is populated by one unit mass of atomistic households that consume products of different varieties and quality. Firms enter and exit the market and produce goods of different quality. Upon entry, each firm produces a single product variety, draws a specific capability level, and pays sunk entry costs, as in Ghironi and Melitz (2005). During each period, firms pay fixed operational costs otherwise terminate production and exit the market, as in Hamano and Zanetti (2014). The firm's capability is associated with a specific quality and productivity level, following the findings in Sutton (1998, 2005). The consumption price index accounts for changes in product variety and quality.

2.1 Households

During each period t, the representative household maximizes expected utility,

$$E_t \sum\nolimits_{i=t}^{\infty} \beta^{i-t} U_t, \tag{1}$$

where $0 < \beta < 1$ is the discount factor. Utility depends on consumption, C_t, and labor supply, L_t, according to $U_t = \ln C_t - \chi L_t^{1+\frac{1}{\varphi}} / (1 + 1/\varphi)$, where $\chi > 0$ is the degree of disutility in supplying labor and φ is the Frisch elasticity of labor supply.

Consumption is defined over a continuum of goods, Ω, and during each period t, only a subset of goods, $\Omega_t \subset \Omega$, is available. Each produced good has a unique variety indexed by $\omega \in \Omega_t$. The consumption aggregator is

$$C_t = V_t \left(\int_{\omega \in \Omega_t} \left(q(\omega) c_t(\omega) \right)^{1-\frac{1}{\sigma}} d\omega \right)^{\frac{1}{1-\frac{1}{\sigma}}}, \tag{2}$$

where $c_t(\omega)$ is individual demand for variety ω, and $q(\omega)$ is the quality of the variety that is invariant across time. In particular, $V_t = S_t^{\psi - \frac{1}{\sigma - 1}}$, where S_t denotes the number of available varieties at time t, and $\sigma > 1$ is the elasticity of substitution among varieties. As in Benassy (1996), ψ represents the marginal utility of an additional increase in the number of varieties in the basket and by imposing $\psi = 1/(\sigma - 1)$ the consumption aggregator (2) nests the standard Dixit-Stiglitz aggregator. The price index that minimizes the consumption expenditure is

$$P_t = \frac{1}{V_t} \left(\int_0^{S_t} \left(\frac{p_t(\omega)}{q_t(\omega)} \right)^{1-\sigma} d\omega \right)^{\frac{1}{1-\sigma}}, \tag{3}$$

where $p_t(\omega)/q_t(\omega)$ is the quality-adjusted individual price of variety ω. Equation (3) is consistent with a welfare-basis index and shows that for a given variety ω, the price index rises (decreases) when the number of available varieties, S_t, or the quality, $q_t(\omega)$, decrease (rises).

The quality-adjusted demand for each variety, ω, is

$$q_t(\omega)c_t(\omega) = V_t^{\sigma-1} \left(\frac{p_t(\omega)/q_t(\omega)}{P_t} \right)^{-\sigma} C_t. \tag{4}$$

where $p_t(\omega)$ denotes the physical unit price of variety ω.

2.2 Quality, production, pricing and producing decision

Firms are indexed by their specific "capability", α. As in Sutton (1998, 2005), each capability level, α, is associated with a firm-specific quality $q(\alpha)$ and productivity level $z(\alpha)$ as $\alpha \equiv q(\alpha) z(\alpha)$. Capability, α, is thus defined as the amount of quality produced per worker in each production unit.

Here we take the simplest step by assuming $q(\alpha) = \alpha^{\phi}$ and $z(\alpha) = \alpha^{1-\phi}$, following Baldwin and Harrigan (2007). Thus, the firm's quality and specific productivity are related:

$$q(\alpha) = z(\alpha)^{\frac{\phi}{1-\phi}}, \tag{5}$$

where the parameter ϕ encapsulate the degree of competition in quality (i.e. "quality ladder"). In particular, if $\phi > 1$ or $\phi < 0$, the correlation between firm-specific quality and productivity is negative. Note that if $\phi = 0$, the quality becomes irrelevant for the dynamics of the model, and firms have the same quality (i.e. $q(\alpha) = 1$). In principle, we can consider a more complex mechanism for the determination of optimal firm-specific quality and derive it as a firm's optimization problem. As argued in Baldwin and Harrigan (2007), however, the optimally chosen quality becomes the function of firm-specific productivity, similar to equation (5).[3]

Production requires an operational fixed cost of f_t units of labor in every period. During each period t, the labor demand, $l_t(\alpha)$, depends on the scale of effective production, $y_t(\alpha)/Z_t z(\alpha)$. Operational fixed costs are defined in terms of effective labor, f_t/Z_t^θ, so that the total labor demand is

$$l_t(\alpha) = \frac{y_t(\alpha)}{Z_t z(\alpha)} + \frac{f_t}{Z_t^\theta}. \tag{6}$$

According to equation (6), fixed costs fluctuate with aggregate labor productivity level, Z_t, with a degree of spillover, θ. Fixed operational costs, f_t, are exogenous and act as proxy (de)regulation in production.

In every period, a number of new entrants, $H_{,t}$, enters the market. Prior to entry, these new entrants are identical and face a sunk entry cost of $f_{E,t}$ effective labor units. Entry cost is therefore equal to $w_t f_{E,t}/Z_t^\vartheta$ units of consumption goods, where w_t is the real wage and ϑ denotes the degree of spillover from aggregate productivity shock. Upon entry, each firm draws a capability level, α, from a distribution, $G(\alpha)$, with support on $[\alpha_{\min}, \infty)$.

Because of fixed operational cost, only a subset of firms with a capability level, α, superior to the cutoff level, $\alpha_{s,t}$, charges sufficiently lower quality-adjusted prices and earns positive profits, despite the existence of fixed operational cost f_t. Destruction of production unit is thus endogenous and depends on the cutoff capability level. In addition to the endogenous destruction, an exogenous depreciation shock, which takes place with probability $\delta \in (0, 1)$, hits producers in every period. This exit-inducing shock is independent of the firm-specific capability level and is assumed to take place at the

[3] Mandel (2010), Kugler and Verhoogen (2012), Johnson (2012) and Antoniades (2012) develop models where firms set the quality level that maximizes profits. They find a functional form that relates firm specific productivity and quality similar to equation (5).

very end of the period. Therefore, $G(\alpha)$ also represents the productivity distribution of all firms that have production potential.

Each firm faces a residual demand curve with constant elasticity, σ, described by equation (4), which affects the production scale. Profit maximization of the firm prices yields the following optimal real prices:

$$\rho_t(\alpha) = \frac{\sigma}{\sigma - 1} \frac{w_t}{Z_t z(\alpha)}. \tag{7}$$

Equation (7) shows that changes in unit real price and unit marginal cost depend on quality ladder, ϕ, since $z(\alpha) = \alpha^{1-\phi}$, for any given capability level. Depending on α, the firm may or may not produce. Thus, using equation (6) and (7), if production materializes, the firm's real profits are

$$d_t(\alpha) = \frac{1}{\sigma} S_t^{\psi(\sigma-1)-1} \left(\frac{\rho_t(\alpha)}{q(\alpha)} \right)^{1-\sigma} C_t - \frac{w_t f_t}{Z_t^\theta}. \tag{8}$$

2.3 Firm average

Given the distribution of capability level, $G(\alpha)$, the mass of producers, N_t, is defined over the productivity levels $[\alpha_{\min}, \infty)$. Among these firms, there are $S_t = [1 - G(\alpha_{s,t})] N_t$ that engage in production after surviving establishment destruction, as described below. Following Melitz (2003) and Ghironi and Melitz (2005), we define the average capability of surviving firms, $\widetilde{\alpha}_{s,t}$, as[4]

$$\widetilde{\alpha}_{s,t} \equiv \left[\frac{1}{1 - G(\alpha_{s,t})} \int_{\alpha_{s,t}}^{\infty} \alpha^{\sigma-1} dG(\alpha) \right]^{\frac{1}{\sigma-1}}, \tag{9}$$

which contains all the information about the distribution of capabilities. Provided this average, we define the average real price of surviving firms as $\widetilde{\rho}_{s,t} \equiv \rho_{s,t}(\widetilde{\alpha}_{s,t})$. Similarly,

[4]We define the average capability level as a harmonic mean weighted by quality-adjusted output. From the goods market clearing condition, we have $[q_t(\alpha_{s,t}) y_t(\alpha_{s,t})] / [q_t(\widetilde{\alpha}_{s,t}) y_t(\widetilde{\alpha}_{s,t})] = (\alpha_{s,t}/\widetilde{\alpha}_{s,t})^\sigma$. Thus, $\widetilde{\alpha}_{s,t}$ can be defined as

$$\widetilde{\alpha}_{s,t}^{-1} \equiv \frac{1}{1 - G(\alpha_{s,t})} \int_{\alpha_{s,t}}^{\infty} \alpha^{-1} \frac{q_t(\alpha_{s,t}) y_t(\alpha_{s,t})}{q_t(\widetilde{\alpha}_{s,t}) y_t(\widetilde{\alpha}_{s,t})} dG(\alpha).$$

we define average real profits for surviving firms as $\widetilde{d}_{s,t} \equiv d_{s,t}\left(\widetilde{\alpha}_{s,t}\right)$, written as

$$\widetilde{d}_{s,t} = \frac{1}{\sigma}\frac{C_t}{S_t} - \frac{w_t f_t}{Z_t^{\vartheta}}. \tag{10}$$

Finally, we define average operational profits among total producers as $\widetilde{d}_t = \left(S_t/N_t\right)\widetilde{d}_{s,t}$.

2.4 Firm entry and exit

We assume that entrants at time t only start producing at time $t+1$. These entrants discount the stream of their expected profits $\left\{\widetilde{d}_i^s\right\}_{i=t+1}^{\infty}$ by using the stochastic discount factor of households adjusted by exogenous exit inducing shock δ. Thus, their expected post entry value is

$$v_t = E_t \sum_{i=t+1}^{\infty} \left[\beta\left(1-\delta\right)\right]^{i-t} \left(\frac{C_i}{C_t}\right)^{-1} \widetilde{d}_i, \tag{11}$$

which represents the share price of equities and mutual funds across different firms. Entry occurs until the expected firm value (11) is equal to the entry cost, leading to the free entry condition,

$$v_t = \frac{w_t f_{E,t}}{Z_t^{\vartheta}}. \tag{12}$$

The timing of entry and of production imply that the number of domestically producing firms evolves according to

$$N_t = \left(1-\delta\right)\left(N_{t-1} + H_{t-1}\right) \tag{13}$$

Establishments that engage in production, S_t, are a subset of the number of total producers, N_t. Therefore, in any given period t, the number of destroyed establishments is the sum of those that are endogenously destroyed, D_t^S, and exogenously destroyed, D_t^{δ}:

$$D_t \equiv D_t^S + D_t^{\delta},$$

where $D_t^S \equiv N_t - S_t$ and $D_t^{\delta} \equiv \delta\left(S_t + H_t\right)$.

2.5 Parametrization of productivity draw

To solve the model we need to assume a distribution of capability levels, α. We assume the following Pareto distribution for $G(\alpha)$:

$$G(\alpha) = 1 - \left(\frac{\alpha_{\min}}{\alpha}\right)^k,$$

where $\alpha_{\min}$ is the minimum productivity level and k ($> \sigma - 1$) determines the shape of the distribution.[5] With this parametrization, we can express the average capability of surviving firms, $\widetilde{\alpha}_{s,t}$, in equation (9) as

$$\widetilde{\alpha}_{s,t} = \alpha_{s,t}\left[\frac{k}{k-(\sigma-1)}\right]^{\frac{1}{\sigma-1}}, \tag{14}$$

and the fraction of surviving producers is

$$\frac{S_t}{N_t} = \alpha_{\min}^k \left[\frac{k}{k-(\sigma-1)}\right]^{\frac{k}{\sigma-1}} \widetilde{\alpha}_{s,t}^{-k}.$$

As mentioned above, one firm that has a cutoff capability level that earns zero profits from production, such that $d_t(\alpha_{s,t}) = 0$, under which production becomes unprofitable. Substituting equation (14) in the firm's real profits (8) yields the equation that determines the cutoff capability level:

$$\frac{1}{\sigma}\frac{C_t}{S_t} = \frac{k}{k-(\sigma-1)}\frac{w_t f_t}{Z_t^{\theta}}. \tag{15}$$

2.6 Household budget constraint and intertemporal problems

We choose the consumption-based price index, P_t, as numéraire. The household receives income by supplying labor, L_t, at the real wage rate, w_t, by acquiring average dividends income among producers, $\widetilde{d}_t$, and by selling its initial share position, v_t, of each mutual fund share holdings, x_t, of producers, N_t. The household spends its income on consumption, C_t, buying x_{t+1} shares of the mutual funds of producers, N_t, and new entrants, H_t,

[5]The parameter k indexes the dispersion of capability across firms. The dispertion decreases as k increases, and the capability levels are concentrated towards the lower bound $\alpha_{\min}$. To ensure that variance of the capability distribution is finite, we assume that $k > \sigma - 1$.

at the share price, v_t. The household budget constraint is thus

$$L_t w_t + x_t N_t \left(v_t + \widetilde{d}_t \right) = C_t + x_{t+1} v_t \left(N_t + H_t \right). \tag{16}$$

During each period t, the representative household chooses consumption, C_t, share holding, x_{t+1}, and the labor supply, L_t, to maximize the expected utility function (1) subject to the budget constraint (16). The first-order conditions with respect to consumption and labor supply yield the standard labor supply equation

$$\chi \left(L_t \right)^{\frac{1}{\varphi}} = w_t C_t^{-1}.$$

The first-order condition with respect to share holdings once it is combined with the firms law of motion (13) and with the first-order condition for consumption yields

$$v_t = \beta \left(1 - \delta \right) E_t \left(\frac{C_{t+1}}{C_t} \right)^{-1} \left(v_{t+1} + \widetilde{d}_{t+1} \right), \tag{17}$$

which, once iterated forward, shows that share prices are an expected discounted sum of future dividends.

2.7 Model equilibrium and solution

To derive the aggregate equilibrium, we impose labor market clearing. Aggregate labor supply, L_t, is employed in either the production of consumption goods (intensive margins, i.e. production scale) or the creation of new firms (extensive margins):

$$L_t = S_t l_t \left(\widetilde{\alpha}_{s,t} \right) + H_t \frac{v_t}{w_t},$$

which can be expressed as[6]

$$L_t = S_t \left[\left(\sigma - 1 \right) \frac{\widetilde{d}_{s,t}}{w_t} + \sigma \frac{f_t}{Z_t^{\theta}} \right] + H_t \frac{v_t}{w_t}. \tag{18}$$

Equation (18) is equivalent to the aggregated accounting identity of GDP obtained by aggregating budget constraints among households, $Y_t \equiv C_t + v_t H_t = L_t w_t + S_t \widetilde{d}_{s,t}$,

[6]Note that $\widetilde{d}_{s,t} = \frac{\widetilde{\rho}_{s,t}}{\sigma} \widetilde{y}_{s.t} - \frac{w_t f_t}{Z_t^{\theta}}$, where $\widetilde{y}_{s,t}$ represents average intensive margins.

where Y_t is real GDP measured in the welfare basis of expenditures and income. The model consists of 13 equations and 13 endogenous variables among which the number of producers, N_t, is a state variable. Finally, we assume that aggregate productivity follows the law of motion, $\ln(Z_t) = \rho \ln(Z_{t-1}) + \varepsilon_t$, where ε_t is a normally distributed innovation with zero mean and variance equal to σ_v^2. Table 1 summarizes the benchmark model.

Table 1: Summary of the benchmark model

Average pricing	$\widetilde{\rho}_{s,t} = \frac{\sigma}{\sigma-1} \frac{w_t}{Z_t \widetilde{z}_{s,t}}$
Quality-adjusted real price	$\widetilde{\rho}_{s,t} / \widetilde{q}_{s,t} = S_t^{\psi}$
Average survivors' profits	$\widetilde{d}_{s,t} = \frac{1}{\sigma} \frac{C_t}{S_t} - \frac{w_t f_t}{Z_t^{\theta}}$
Average profits	$\widetilde{d}_t = \frac{S_t}{N_t} \widetilde{d}_{s,t}$
Free entry condition	$v_t = \frac{w_t f_{E,t}}{Z_t^{\vartheta}}$
Motion of firms	$N_{t+1} = (1-\delta)(N_t + H_t)$
Euler equation	$v_t = \beta (1-\delta) E_t \left(\frac{C_{t+1}}{C_t} \right)^{-1} \left(v_{t+1} + \widetilde{d}_{t+1} \right)$
Optimal labor supply	$\chi (L_t)^{\frac{1}{\varphi}} = w_t C_t^{-1}$
ZCP	$\frac{1}{\sigma} \frac{C_t}{S_t} = \frac{k}{k-(\sigma-1)} \frac{w_t f_t}{Z_t^{\theta}}$
Schumpeterian surviving rate	$\frac{S_t}{N_t} = \alpha_{\min}^{k} \left[\frac{k}{k-(\sigma-1)} \right]^{\frac{k}{\sigma-1}} \widetilde{\alpha}_{s,t}^{-k}$
Labor market clearing	$L_t = S_t \left[(\sigma-1) \frac{\widetilde{d}_{s,t}}{w_t} + \sigma \frac{f_t}{Z_t^{\theta}} \right] + H_t \frac{v_t}{w_t}$
Average quality	$\widetilde{q}_{s,t} = \widetilde{\alpha}_{s,t}^{\phi}$
Average productivity	$\widetilde{z}_{s,t} = \widetilde{\alpha}_{s,t}^{1-\phi}$

The equilibrium conditions do not have an analytical solution. Consequently, we approximate the system by loglinearizing its equations around the stationary steady state. In this way, a linear dynamic system describes the path of the endogenous variables' relative deviations from their steady-state value, accounting for the exogenous shocks.

3 Equilibrium price bias

Feenstra (1994) and Broda and Weinstein (2010) derive a measure of welfare-consistent price inflation that nests CES preference. Similarly, our corresponding measure of welfare-consistent (gross) price inflation is P_{t+1}/P_t. We can express the welfare-based price index (3) as a function of average individual price and quality as well as the number of product varieties, $P_t = \widetilde{p}_{s,t}/(S_t^{\psi}\widetilde{q}_{s,t})$, and use it to determine the total bias in price changes as the difference between average inflation, $\widetilde{\pi}_{s,t+1}$, and welfare-consistent inflation, π_{t+1}:

$$\widetilde{\pi}_{s,t+1} - \pi_{t+1} = \underbrace{\psi\left(\widehat{S}_{t+1} - \widehat{S}_t\right)}_{\text{Variety bias}} + \underbrace{\left(\widehat{\widetilde{q}}_{s,t+1} - \widehat{\widetilde{q}}_{s,t}\right)}_{\text{Quality bias}}, \tag{19}$$

where $\widetilde{\pi}_{s,t+1} = \widehat{\widetilde{p}}_{s,t+1} - \widehat{\widetilde{p}}_{s,t}$ is the change in average prices, $\pi_{t+1} = \widehat{P}_{t+1} - \widehat{P}_t$ is the change in welfare-consistent prices, and hats denote log-deviations from the steady state. Equation (19) shows that fluctuations in the price bias depend on movements in product variety and quality and that the extent to which changes in product variety affect the price bias depends on the preference for variety, controlled by the parameter ψ. By using equation (19) in the context of the fully-defined general equilibrium model, we can study how exogenous productivity shocks and changes to the underlying structure of the economy affect fluctuations in the price bias. Importantly, equation (19) is able to disentangle how the contribution of product quality and variety in the measure of prices bias changes over time. To the best of our knowledge, this is the first study that quantifies the two sources of price bias and investigate their cyclical properties in the context of a general equilibrium model.

4 Results

In this section, we investigate the effect of product quality and variety on the price bias using the general equilibrium model. After calibrating the model, we study the cyclical properties of the price bias and disentangle the contribution of product quality and variety. We also focus on the effect of price bias on the measure of cyclical fluctuations. Finally, we examine the effect of permanent entry deregulation on the price bias.

4.1 Calibration

To produce a quantitative assessment of the theoretical framework, we assign numerical values to the model's parameters, summarized in Table 2.

Table 2: Calibration of the model

β	Discount factor	0.99
φ	Frisch elasticity of labor supply	2
σ	Elasticity of substitution among varieties	3.8
k	Distribution parameter	3.4
ψ	Marginal utility of an increase in varieties	0.36
ϕ	Quality ladder	-1.98
χ	Disutility of supplying labor	0.8549
$\alpha_{\min}$	Minimum idiosyncratic capability level	1
δ	Exogenous destruction rate	0.0025
A	Steady-state level of aggregate productivity	1
ρ	Persistence of aggregate productivity	0.979
σ_v	Standard deviation of productivity shocks	0.0072
f_E	Steady-state fixed entry costs	1
f	Steady-state value of subsidies	0.0017
θ	Propagation on fixed operational cost	0.237
ϑ	Propagation on entry cost	0.203

We calibrate the model on quarterly frequencies. We set the value of discount factor, β, and the Frisch elasticity of labor supply, φ, to 0.99 and 2, respectively. These values are within the range of those used in the literature. We set the elasticity of substitution among varieties, σ, to 3.8, as in Ghironi and Melitz (2005), based on empirical findings on U.S. manufacturing in Bernard et al. (2003). We calibrate the parameter k that determines the shape of the distribution of firm-specific capability, as in Ghironi and Melitz (2005). We set the parameter that establishes the marginal utility of an increase in the number of varieties, ψ, to 0.36 (since $\psi = 1/(\sigma - 1)$), consistent with the standard

Dixit-Stiglitz preferences. We set the parameter that determines the quality ladder, ϕ, to -1.98 to generate an equilibrium annual CPI bias of 0.8 percent, as estimated in Broda and Weinstein (2010). For the version of the homogenous quality version of the model, we set the degree of competition in quality equal to zero ($\phi = 0$). We set the value of the disutility of supplying labor, χ, to 0.8549 to deliver a steady state labor supply equal to one. We normalize A, f_E, and $\alpha_{\min}$ to one.

We calibrate the total rate of establishment destruction to match the average annual exit rate for all U.S. establishments of 0.11 from BDS data for the period 1977 to 2011. Therefore, we set the exogenous destruction rate, δ, to 0.0025, implying that, on average, one percent of producers are exogenously destroyed per year. We set the steady-state value of subsidies, f, to 0.0017, which implies the endogenous destruction rate, $1 - S/N$, is equal to 0.025. The value of the exogenous and endogenous destruction rates imply that, on average, 11 percent of producers are endogenously destroyed per year, as observed in the data.

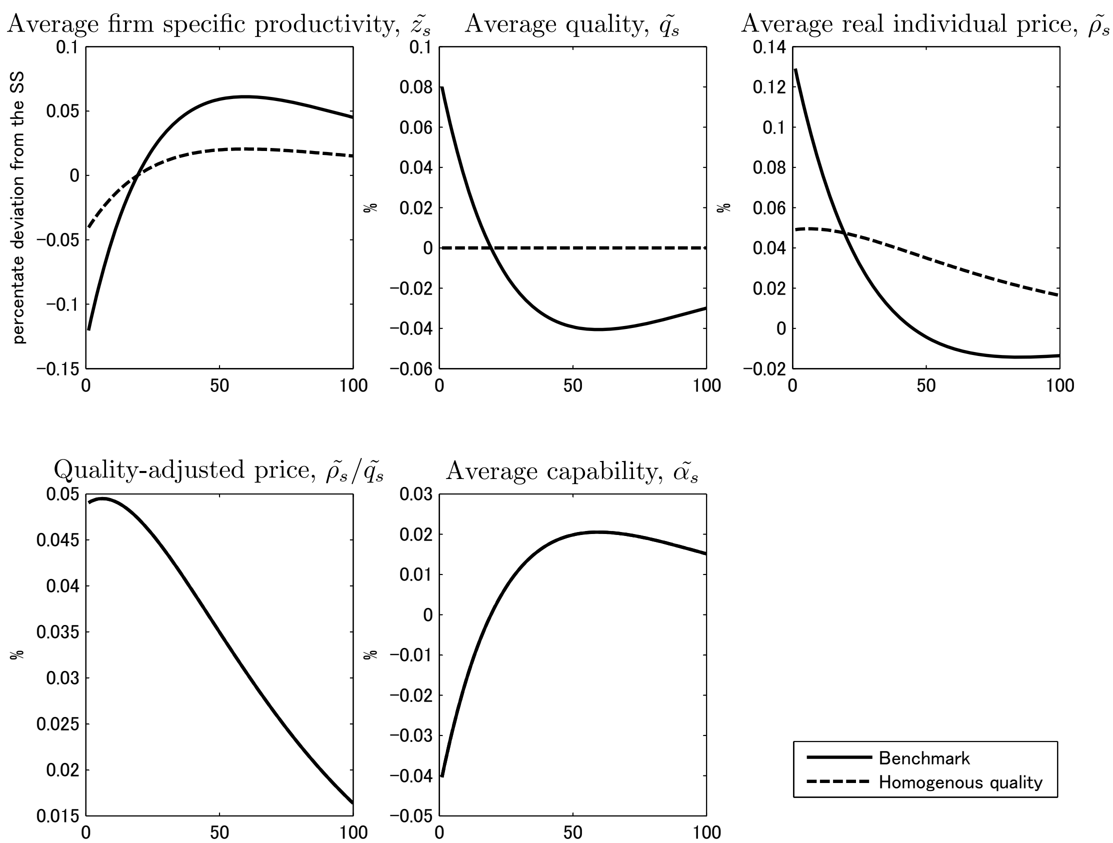
We set the endogenous destruction rate, $1 - S/N$, to 0.025, implying that, on average, ten percent of producers are endogenously destroyed per year. To achieve this calibration, we set the steady state value of subsidies, f, to 0.0017.

We set the persistence parameter, ρ, and the standard deviation of innovations, σ_{υ}, to 0.979 and 0.0072, respectively, as in King and Rebelo (1999). The coefficients that govern the propagation of productivity on fixed operational costs, θ, and entry costs, ϑ, are set to minimize the distance between some key moments in the observed data and those implied by the theoretical model. In particular, we numerically solve $J = \min_{\theta,\vartheta} \left[\widehat{\Psi} - \Psi\left(\theta, \vartheta\right)\right]' V^{-1} \left[\widehat{\Psi} - \Psi\left(\theta, \vartheta\right)\right]$, where $\widehat{\Psi}$ is the vector containing the standard deviation of establishment entry and exit in the data, $\Psi\left(\theta, \vartheta\right)$ is the vector containing the corresponding standard deviation implied by the theoretical model and V^{-1} is the inverse of the variance-covariance matrix of empirical data for establishment entry and exit. This procedure gives the value of $\theta = 0.237$ and $\vartheta = 0.203$.

4.2 Cyclical properties of price bias

We use the general equilibrium model to investigate the cyclical properties of the price bias and to differentiate the contribution of product quality and variety. In this model, exogenous shocks to technology generate cyclical fluctuations. We isolate the effect of changes in quality by comparing the benchmark version of the model that embeds both product quality and variety against the alternative model with homogenous quality (i.e. $\phi = 0$).

Figure 1: Responses of selected variables to a productivity shock



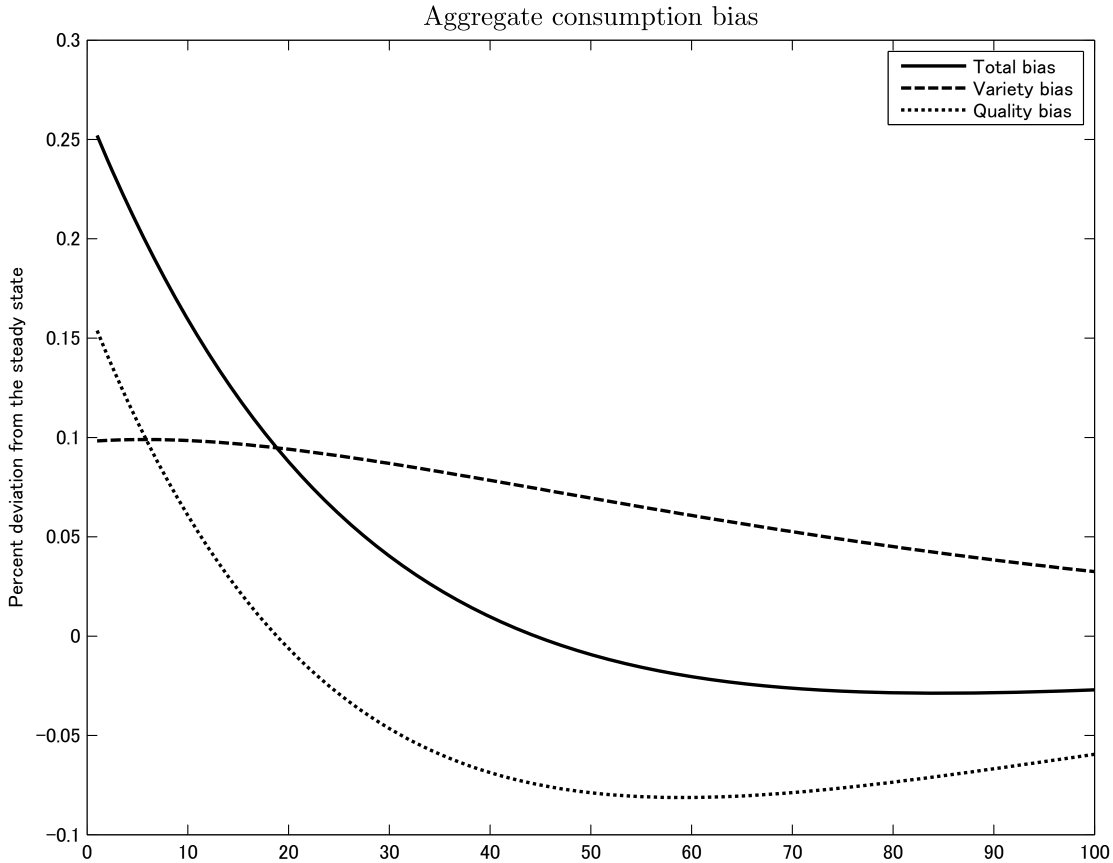
Notes: Each entry shows the percentage-point response of one of the model's variables to a one-percentage deviation of the shock for the benchmark model (solid line) and the model with homogeneous quality (dashed line).

Since movements in the price bias depend on fluctuations in product quality and variety, it is instructive to outline how the model reacts to the technology shock before we focus on the price bias. Figure 1 shows the responses of key variables to a positive productivity shock for the benchmark model (solid line) and the model with homogenous quality (dashed line). On impact, the positive technology shock lowers the producer's average capability, $\widetilde{\alpha}_{s,t}$, which, in turn, increases the producer's average quality, $\widetilde{q}_{s,t}$, and reduces firm-specific productivity, $\widetilde{z}_{s,t}$, in accordance with equation (5). The increase in average marginal cost raises real prices, $\widetilde{\rho}_{s,t}$, to a greater extent in the model that accounts for product quality. In response to the shock, entry occurs, and the producer's profit increases more than cost. Therefore, the number of producers, S_t, in the economy also increases. Note that the increase in the number of producers is the same in both models since firms have the same marginal cost of production once costs are adjusted for quality in the benchmark model. Since the quality-adjusted price, $\widetilde{\rho}_{s,t}/\widetilde{q}_{s,t}$, which depends on firm-specific capability alone, increases in exactly the same way in the two models, average profits and therefore the number of surviving producers is the same in both models. Overall, the dynamics of the models show that firms with costly technology enter the market in periods of high aggregate demand and produce high quality goods. Therefore, the average level of quality and the number of varieties is pro-cyclical in the model, similar to the data as estimated in Broda and Weinstein (2010).

We can now use the insights from the model's dynamics to focus on the cyclical properties of the aggregate price bias. Figure 2 shows the bias in aggregate prices (solid line) and the share of the bias due to product quality (dotted line) and variety (dashed line). A few interesting findings emerge. First, the price bias in quality is pro-cyclical during short to medium horizons, but it becomes counter-cyclical at longer horizons. Movements in the contribution of product variety to the price bias are pro-cyclical and display high persistence. In response to a positive productivity shock, new firms find it profitable to enter the market, and as a result, the number of varieties increases. However, it takes time to create a new variety due to the assumption of time to build embedded in equation (13), which generates a persistent dynamics in the number of available varieties.

What is the effect of price bias on the measure of cyclical fluctuations? To answer

Figure 2: Responses of the aggregate price bias to a productivity shock



Notes: Each entry shows the percentage-point response of the aggregate price bias (solid line) and the share of the bias due to product quality (dotted line) and variety (dashed line) to a one-percentage deviation of the technology shock.

this question, we compare the second moments of real variables deflated by the welfare-consistent prices, P_t, against those of empirically based prices, $P_{e,t}$. To derive such a measure, for any variable X_t, we deflate the corresponding real variable by the average price index as $X_{R,t} \equiv P_t X_t / P_{e,t}$. Using this method we define the empirically-based aggregate output, $Y_{R,t}$, consumption, $C_{R,t}$, and investment, $I_{R,t}$.[7]

Table 3 provides second moments of selected variables for the U.S. data for the bench-

[7] Investment is defined as: $I_{R,t} \equiv v_{R,t} H_t$.

Table 3: Second moments

		Y_R	C_R	I_R	L	H	D	*Bias*
St. dev. (%)	U.S. Data	1.23	0.93	5.30	1.83	4.19	4.68	n/a
	Benchmark	0.95	0.73	4.83	0.19	4.21	4.69	0.24
	Homogenous quality	1.03	0.80	4.91	0.19	4.21	4.69	0.09
Relative to Y_R	U.S. Data	1.00	0.75	4.30	1.49	3.40	3.80	n/a
	Benchmark	1.00	0.77	5.08	0.20	4.42	4.93	0.25
	Homogenous quality	1.00	0.78	4.78	0.18	4.10	4.56	0.09
Corr(Y_R. X)	U.S. Data	1.00	0.88	0.93	0.92	0.68	-0.15	+*
	Benchmark	1.00	1.00	1.00	0.99	0.99	-0.98	0.99
	Homogenous quality	1.00	1.00	1.00	0.99	1.00	-0.98	1.00

mark and the homogenous-quality economies.[8] The data values with an asterisk are taken from Broda and Weinstein (2010). The models replicate the second moments in the data fairly well. In particular, since the determination of product variety is endogenous, the model is able to replicate movements in product creation and destruction. Product creation is pro-cyclical whereas product destruction is counter-cyclical, in line with Broda and Weinstein (2010). However, the correlations in the model are higher than the ones in the data.[9]

Broda and Weinstein (2010) establish that official statistics understate cyclical fluctuations due to their biased measure of aggregate price. The second moments of the theoretical model in the table corroborate this fact. For the benchmark model, the second moments omit fluctuations in product quality and variety. On the other hand, the

[8] All series are detrended by the HP filter, using a smoothing parameter equal to 1600. Second moments of the theoretical models are computed by the frequency domain technique in Uhlig (1998). Appendix B reports data sources.

[9] The presence of adjustment costs on the creation for product creation and destruction would certainly improves the performance of the model. This is also related to the transmission of aggregated productivity shocks on entry and fixed operational costs. The standard deviation and correlation for product destruction are sensitive to cyclical properties of fixed operational cost $w_t f_t / A_t^{\vartheta}$ and entry cost $w_t f_{E,t} / A_t^{\vartheta}$. See Hamano and Zanetti (2014) for a detailed discussion of the issue.

homogenous quality model does account for variety bias, but the second moments omit fluctuations in product variety. The table shows that by omitting changes in both product quality and variety, aggregate variables become less volatile than those in the model with homogenous quality due to the procyclicality of bias. Hence, measurements of cyclical fluctuations derived using the conventional consumption deflator that abstracts from changes in both product quality and variety under-estimate the variables' true volatility in welfare-consistent measure.

The last column in the table shows that the standard deviation of the bias is significantly lower in the model with homogenous quality compared to the benchmark model, suggesting that product quality predominantly drives movements in the bias. Finally, both models deliver a strong pro-cyclical price bias, in line with the empirical findings in Broda and Weinstein (2010). Since these result depend on the marginal utility of an increase in variety, ψ, and the quality latter parameter, ϕ, Appendix C shows the sensitivity of the results to alternative calibrations of these parameters.

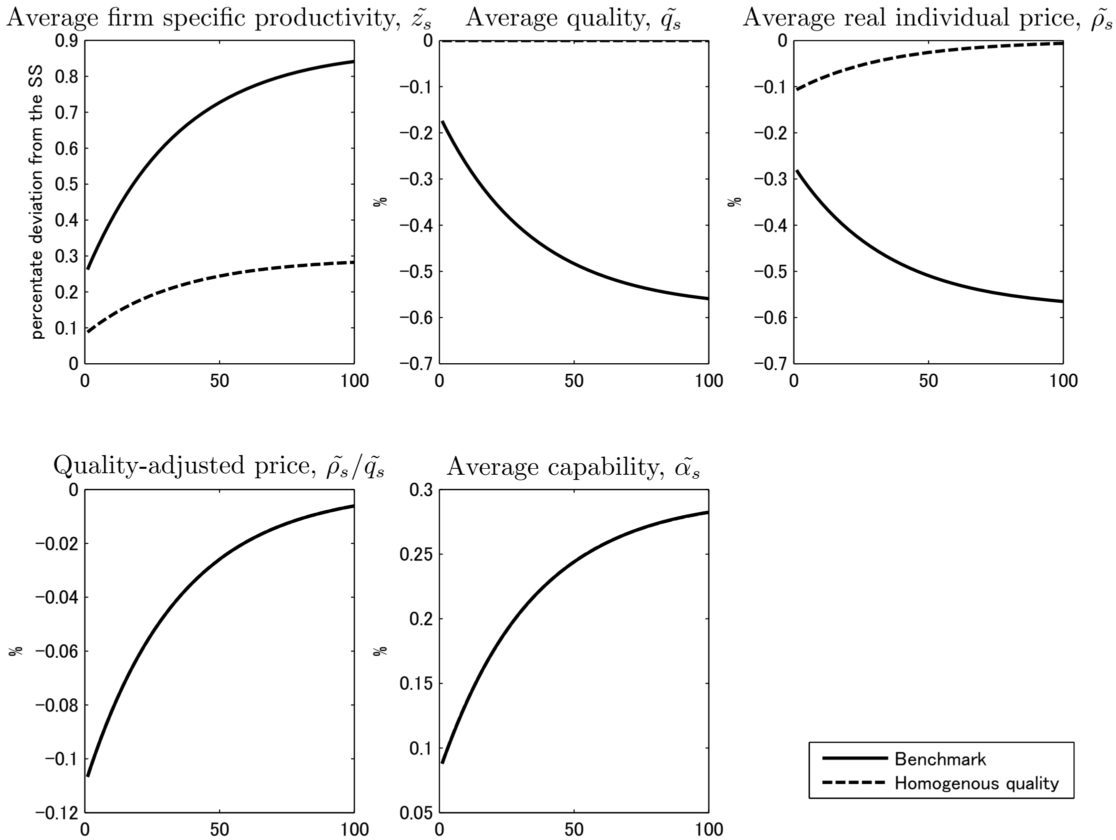
4.3 Permanent entry deregulation and the price bias

In the model, entry deregulation significantly affects the product variety because it affects the firm's incentive to create new varieties of different quality.[10] It is therefore interesting to use the model to investigate the effect of permanent entry deregulation on the price bias. Figure 3 shows selected variables' responses to a one-percent reduction in sunk entry costs, $f_{E,t}$, for the the benchmark version of the model that embeds both product quality and variety (solid line) against the alternative model with homogenous quality (dashed line). Note that in this case the change in deregulation leads the economy to a new steady state.

A permanent decrease in entry costs induces a long-lasting increase in the creation of establishments, H_t, which increases labor demand and generates a permanent rise in wages, w_t. Higher labor costs increase the destruction of product variety, D_t, and require

[10]Cacciatore et al. (2013) show that market deregulation generates static and dynamic distortions that that call for active monetary policy in the long run and over the business cycle.

Figure 3: Permanent entry deregulation



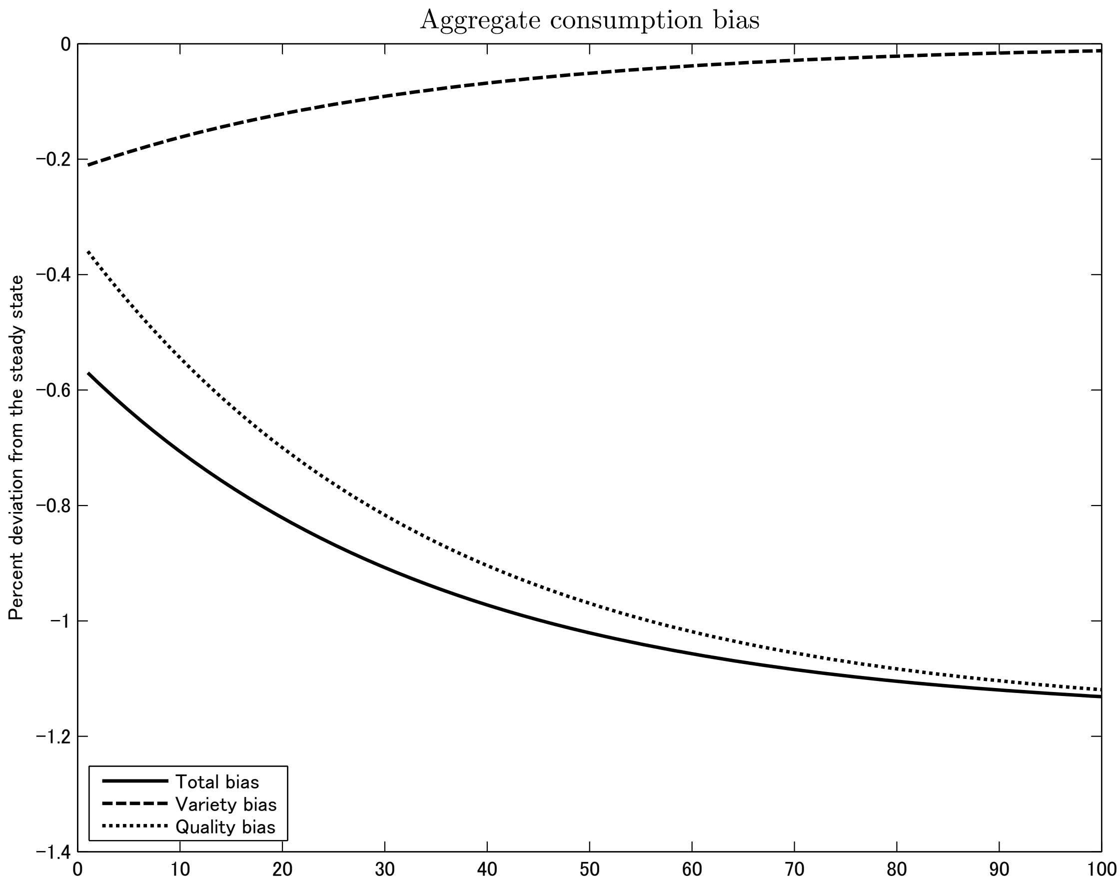
Notes: Each entry shows the percentage-point response of one of the model's variables to a permanent deregulation for the benchmark model (solid line) and the model with homogeneous quality (dashed line).

higher firm-specific average capability, $\widetilde{\alpha}_{s,t}$, to maintain the firm's profitability. At the same time, higher firm-specific capability reduces the firm's average quality, $\widetilde{q}_{s,t}$, and increases firm-specific productivity, $\widetilde{z}_{s,t}$, generating a lower marginal cost, $\widetilde{\rho}_{s,t}$ at the new steady state. Since the quality-adjusted price, $\widetilde{\rho}_{s,t}/\widetilde{q}_{s,t}$, which depends on firm-specific capability alone, increases in exactly the same way in the two models, average profits and therefore the number of surviving producers is the same across the benchmark model and the model with homogenous quality. In the benchmark model with heterogeneous quality, however, the increase in firm-specific productivity is stronger than in the homogenous quality model. In the benchmark model, the negative correlation between quality and productivity implies that firms employ costly technology to produce high quality goods. Therefore, firms with high specific-productivity are able to remain in the market. In addition, average prices return to their original steady state in the homogenous quality model, but they remain permanently lower in the benchmark model. This happens because average firm-specific productivity increases more at the expense of permanently lower average quality in the benchmark model compared to the rise in average firm-specific productivity in the homogenous quality model.

Note that permanent deregulation changes the characteristics of firms in the market in both the benchmark model and the homogenous quality model. In both models, the total number of producers, S_t, remains almost unchanged since the higher creation rate of new product varieties induced by lower entry costs is counterbalanced by higher product destruction due to the increase in the average product capability required to maintain the firm's profitability. However, in the new equilibrium, the aggregate characteristics of firms is different across the two models. In the homogeneous quality model, firms with higher productivity remain in the market. In the model with heterogeneous quality, firms with low marginal cost that produce lower quality goods are able to remain in the market and the effect of higher competition reduces marginal cost and quality.

Figure 4 shows the transitory dynamics of bias in aggregate prices (solid line) and the share of the bias due to product quality (dotted line) and variety (dashed line). Long-run movements in the average price bias are primarily driven by the quality bias, which remains lower in the aftermath of the deregulation period while variety bias returns to its original equilibrium. As discussed above, in response to permanent deregulation, the number of product varieties remains substantially unchanged in the long run and is driven by two opposing effects. On the one hand, deregulation fosters the creation of new product varieties, and on the other hand, product destruction increases since firms need higher average capability to remain profitable. In the short run, product variety falls, driven by the higher level of capability level required for the firm to remain profitable. However, in the long run, firms find it profitable to re-enter the market. All of these effects compensate each other, and the long-run contribution of variety bias to the aggregate price bias is limited. In addition, the figure shows that short-run movements in quality bias are twice as sizeable as movements in variety bias. The sizeable change in quality bias results from the permanent fall in average quality, triggered by the permanent change in deregulation. These findings shows that permanent entry deregulation change the average characteristic of the firms in the market and quality bias drives the bulk of movements in the aggregate price bias.

Figure 4: Responses of the aggregate price bias to a permanent entry deregulation



Notes: Each entry shows the percentage-point response of the aggregate price bias (solid line) and the share of the bias due to product quality (dotted line) and variety (dashed line) to a one-percentage deviation of the technology shock.

5 Conclusion

This paper develops a general equilibrium model that embeds endogenous product quality and variety and assesses their impact on the aggregate price bias. The analysis shows that the aggregate price bias is pro-cyclical, driven by pro-cyclical movements in product quality and variety. The contribution of product quality becomes counter-cyclical in the medium to long run whereas the contribution of product variety is pro-cyclical and highly persistent throughout the business cycle.

The model provides insights into the effect of permanent entry deregulation on product variety and quality and consequently on changes in the bias of aggregate prices. The analysis shows that permanent entry deregulation reduces the aggregate price bias due to the increase in the reduction of product variety and the decline in product quality. However, the reduction of product variety is transitory and is triggered by the increase in wages. Subsequently, the capability level needed to maintain profitability increases while product quality falls because the firm needs costly technology to manufacture high quality goods. Since there is no empirical evidence on the long-run effect of deregulation on the aggregate price bias, confronting the predictions of the theoretical model with the data remains an outstanding task for future research.

To simplify the analysis, our model assumes that each firm produces a distinct product variety. However, Broda and Weinstein (2010) document that turnover of product variety may take place within firms. Extending the model to include multi-product variety and an endogenous determination of product quality, as in Bernard et al. (2010) and Eckel and Neary (2010), would certainly be a useful extension for future research. Finally, the analysis is based on a closed economy model that abstracts from the effect of foreign producers. The presence of foreign firms, however, is potentially important for adjustments in product quality and variety in the aggregate price index, and thus also for changes in the aggregate price bias. Extending the analysis to consider this additional channel remains a task for future research.

Appendix A: Steady state

We start by deriving the steady state of the benchmark model. The Euler equation (17) provides

$$\frac{1}{\beta} = (1-\delta)\left(1+\frac{\widetilde{d}}{v}\right). \tag{20}$$

Using the equation of average profit of surviving firms (10) and the equation that determines the cutoff capability level (15), we write equation (20) as

$$\frac{\widetilde{d}_s}{w} = \frac{\sigma-1}{k-(\sigma-1)}. \tag{21}$$

From the definition of operational profits among producers, we have $\widetilde{d} = S\widetilde{d}_s/N$, and the free entry condition (12) implies $v = w$. Using these relations, we can express equation (20) as

$$\frac{1}{\beta} = (1-\delta)\left(1+\frac{S}{N}\frac{\sigma-1}{k-(\sigma-1)}f\right), \tag{22}$$

which provides the steady state endogenous destruction rate, S/N, given operational fixed costs, f.

We set the value of χ so that the steady state labor supply is one. From the law of motion of producers (13), we derive the number of new entrants, $H = \delta N/(1-\delta)$. Using these relations in the labor market clearing condition (18), it yields

$$\frac{1}{N} = (\sigma-1)\frac{S}{N}\frac{\sigma-1}{k-(\sigma-1)}f + \sigma\frac{S}{N}f + \frac{\delta}{1-\delta}, \tag{23}$$

which provides a unique solution for the number of producers, provided the endogenous destruction rate, S/N. Once the value S is obtained, the steady state values of other variables is straightforward to derive.

Appendix B: Data

The data on establishment entry and exit are taken from private sector establishment births and deaths, reported by the Bureau of Labor Statistics (BLS).[11] For each variable, the mnemonics and data source are:

[11]The dataset is available at the web address http://www.bls.gov/web/cewbd/table9_1.txt.

Domestic Product, GDP, BEA.

Fixed Private Investment, FPI, BEA.

Personal Consumption Expenditures: Services, PCESV, BEA.

Personal Consumption Expenditures: Nondurable Goods, PCND, BEA.

Gross Domestic Product: Implicit Price Deflator, GDPDEF, BEA.

All Employees: Total Nonfarm, PAYEMS, BLS.

Average Weekly Hours of Production and Nonsupervisory Employees: Manufacturing, AWHMAN, BLS.

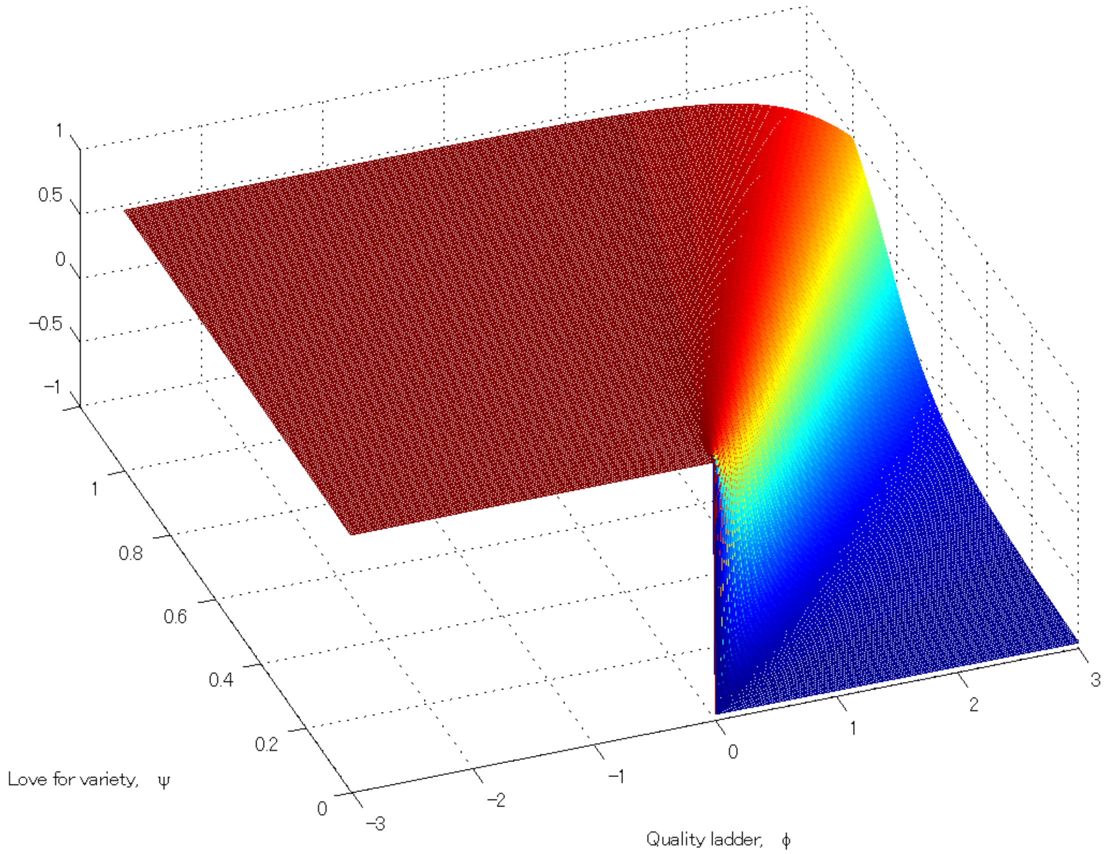
Appendix C: Sensitivity analysis

In this appendix, we perform sensitivity analysis on how values for the parameters controlling the quality ladder parameter (ϕ) and the preference for variety parameter (ψ) affect the correlation of the aggregate price bias with the empirically consistent measure of output, $Y_{R,t}$. Figure 5 shows how different values for the quality ladder, ϕ, and preference for variety, ψ, affect the correlation between output and the aggregate price bias. Total bias is highly pro-cyclical when $\phi < 0$, and it becomes highly counter-cyclical when $\phi > 0$, provided that the value of ψ is sufficiently low.

As discussed in Section 2, the sign of ϕ determines how average product quality, $\widetilde{q}_{s,t}$, changes in response to movements in average capability, $\widetilde{\alpha}_{s,t}$, shown in equation (5). If $\phi < 0$ in the aftermath of a positive productivity shock, average capability, $\widetilde{\alpha}_{s,t}$, decreases, and therefore, average quality, $\widetilde{q}_{s,t}$, increases as shown in Figure 1. At the same time, the empirically consistent measure of output, $Y_{R,t}$, and the number of varieties, S_t, increase. An increase in quality and number of varieties generates a pro-cyclical pattern of aggregate price bias.

On the opposite, If $\phi > 0$ in the aftermath of a positive productivity shock, the empirically consistent measure of output, $Y_{R,t}$ and the number of varieties increases while the average quality, $\widetilde{q}_{s,t}$, decreases. The contribution of quality bias to aggregate price bias is larger for the broader range of values for the preference for variety (ψ), inducing

Figure 5: Sensitivity analysis



Notes: The figure shows how different values for the quality ladder, ϕ, and preference for variety, ψ, affect the correlation between output and the aggregate price bias.

a conter-cyclical pattern of aggregate price bias. As the value of preference for variety increases, however, the pro-cyclical contribution from the rise in the number of varieties increases as well as counteracting the fall in average quality in total bias.

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