Pricing under Fairness Concerns

Erik Eyster, Kristof Madarasz, Pascal Michaillat*

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This paper proposes a theory of pricing consistent with two well-documented patterns: customers care about fairness, and firms take these concerns into account when they set prices. The theory assumes that customers find a price unfair when it carries a high markup over cost, and that customers dislike unfair prices. Since markups are not observable, customers must extract them from prices. The theory assumes that customers infer less than rationally: when a price rises after an increase in marginal cost, customers partially misattribute the higher price to a higher markup—which they find unfair. Firms anticipate this response and trim their price increases, which reduces the passthrough of marginal costs into prices below one: prices are somewhat rigid. Embedded in a New Keynesian model—as a replacement of Calvo pricing—our theory produces monetary nonneutrality. When monetary policy loosens and inflation rises, customers misperceive markups as higher and feel unfairly treated; firms mitigate the perceived unfairness of prices by reducing their markups, which in general equilibrium leads to higher output.

1. Introduction

Abundant evidence suggests that firms show restraint when setting prices to avoid alienating customers, who balk at paying prices that they regard as unfair. Yet pricing models only rarely include fairness considerations.[1] This is problematic because pricing models are used to analyze policy in industrial organization, international trade, public economics, and macroeconomics—notably in the context of monetary policy. Since the policy implications of these models depend on their welfare properties, which in turn depend on the models' microfoundations, having a model that conforms to customers' and firms' motivations may prove beneficial.

This paper develops a theory of pricing that incorporates such fairness concerns. The first element of our theory is that customers dislike paying prices marked up heavily over marginal costs because they find these prices unfair. This assumption draws upon evidence from numerous surveys of consumers and firms, our own survey of French bakers, and religious and legal texts, which document that customers recoil at paying high markups, and that firms understand this (section 2). Formally, when customers buy a good at price P whose marginal cost is perceived to be MC^p, they deem its markup to be $K^p = P/MC^p$. Customers then weight each unit of consumption of the good by a factor $F(K^p)$ in their utility function. The fairness function $F(K^p)$ is decreasing since higher markups seem less fair; it is concave since people tend to respond more strongly to increases in markups than to decreases.

Because customers do not observe firms' costs, their perceptions of fairness depend upon their estimates of these costs. Our theory takes as its second premise that customers update their beliefs about firms' marginal costs less than rationally: they form beliefs about marginal costs that lie somewhere between their prior beliefs and rational beliefs. This assumption draws upon evidence that during inflationary periods people seem to underinfer increases in nominal costs, and more generally that people tend to infer less than they should about others' private information from others' actions (also in section 2). Formally, we assume that upon observing a price P, customers misperceive the monopoly's true marginal cost as $MC^p = (MC^b)^\gamma \times [(\epsilon - 1)P/\epsilon]^{1-\gamma}$, where MC^b represents customers' prior expectation of the marginal cost and ϵ is the elasticity of demand for customers unconcerned with fairness.

The formula for MC^p embeds two distinct forms of error. First, customers underinfer marginal costs from price by clinging to their prior beliefs. The parameter $\gamma \in (0, 1]$ measures the degree of such underinference. When $\gamma = 1$, customers are completely naive in the sense of inferring

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[1]Fairness has received more attention in other contexts: Akerlof (1982), Akerlof and Yellen (1990), and Benjamin (2015) add fairness to labor-market models; Rabin (1993), Fehr and Schmidt (1999), and Charness and Rabin (2002) to game-theoretic models; and Fehr, Klein, and Schmidt (2007) to contract-theoretic models. For surveys of the economic literature on fairness, see Fehr and Gachter (2000), Sobel (2005), and Fehr, Goette, and Zehnder (2009).

nothing from prices. When $\gamma \in (0,1)$, customers do infer something from price; and insofar as they infer something, they infer that marginal cost is proportional to price. Such proportional inference represents a second error: underinference pertains to how much customers infer, whereas proportional inference describes what customers infer in as much as they do infer. In the limiting case in which $\gamma = 0$, the monopoly optimally sets the markup $\epsilon/(\epsilon - 1)$, which makes $(\epsilon - 1)P/\epsilon$ the marginal cost at price P, and proportional inference agrees with rational inference. However, when $\gamma \in (0,1)$, the monopoly does not find it optimal to mark up proportionally, and proportional inference becomes an error. Because our inference rule geometrically averages underinference with proportional inference, we dub it subproportional inference.

We begin our analysis in section 3 by embedding these psychological elements into a model of monopoly pricing. The monopoly charges a markup over marginal cost, which is a decreasing function of the price elasticity of demand. If customers did not care about fairness, the price elasticity of demand would be the preference parameter ϵ, and the monopoly would mark price up over marginal cost by a constant factor $\epsilon/(\epsilon - 1)$. With such constant markup, prices would be flexible: they would move one-for-one with marginal costs. If customers care about fairness but rationally invert price to uncover the hidden marginal cost, the same pricing rule is an equilibrium. The reason is that when price increases by $x\%$, customers infer that marginal cost has increased by $x\%$, and therefore that the markup has not changed. Since the price change does not change the perceived markup, the price elasticity of demand and thus the markup do not change.

Once fairness concerns and subproportional inference are combined, however, pricing changes. First, fairness concerns and subproportional inference lead the monopoly to set a markup lower than $\epsilon/(\epsilon - 1)$. Indeed, under fairness concerns, demand decreases in price not only due to the standard substitution effect, but also through the fairness channel: a higher price raises the perceived markup, which lowers the marginal utility of consumption. This renders demand more elastic than it would be otherwise, and the monopoly optimally sets a lower markup.

Second, fairness concerns and subproportional inference give rise to price rigidity. After an increase in price spurred by higher marginal cost, customers underappreciate the increase in marginal cost and partially misattribute higher prices to higher markup. Since the fairness function F is more elastic at higher perceived markup, the demand curve is more price elastic at the higher price. (A linear, decreasing, positive function always has increasing elasticity; this is even more true of a concave, decreasing, positive function.) The monopoly therefore optimally reduces its markup after the cost increase. As rising marginal costs bring about price increases that are less than proportional to the increase in marginal cost, the passthrough of marginal costs into prices falls short of one—a mild form of price rigidity, consistent with the response of prices to marginal-cost shocks estimated in several empirical studies.

The finding that fairness concerns lead to price rigidity is reminiscent of the result obtained by Rotemberg (2005) in a pioneering study on the implications of fairness for pricing.[2] He assumes that customers care about firms' altruism—firms' taste for increasing customers' welfare—which they re-evaluate following every price change. Customers buy a normal amount from a firm unless they can reject the hypothesis that the firm is altruistic, in which case they withhold all demand in order to lower the firm's profits. Firms react to the discontinuity in demand by refraining from passing on small cost increases, creating price stickiness. We depart from Rotemberg's discontinuous, buy-normally-or-buy-nothing formulation to one in which customers continuously reduce demand as the unfairness of the transaction increases. The greater tractability of our continuous formulation allows us to obtain closed-form expressions for the markup and passthrough and to embed our pricing theory into a macroeconomic model.

Price-rigidity theories are a key input into monetary models. To illustrate how our theory can be embedded into such a model, and develop its implications, in section 4 we substitute it for Calvo (1983) pricing in a textbook New Keynesian model. In this dynamic model, customers form beliefs about current marginal costs by averaging their past beliefs with their proportional inferences from current prices. This exercise yields three realistic properties. First, monetary policy is nonneutral: it affects output and employment. This property arises through the same channel as in the monopoly model: expansionary monetary policy increases prices and nominal marginal costs; customers partially misattribute higher prices to higher markups, which they perceive as unfair; as a result, the price elasticities of the goods demands rise; firms respond by reducing markups, thus stimulating the economy. Second, the Phillips curve is hybrid: it links current employment not only to current and expected future inflation but also to past inflation. This property emerges because beliefs about nominal marginal costs are backward-looking, forcing firms to account for both future and past inflation when they set prices. Third, when we calibrate the parameters that govern fairness concerns and subproportional inference to match evidence on passthrough, simulating the model yields reasonable impulse responses to monetary-policy shocks. In particular, the impulse responses of output and employment are hump-shaped.

Finally, in section 5, we conclude by exploring some possible welfare implications of our pricing theory, especially for monetary policy.

Our approach to fairness differs from the popular social-preference approach, developed by Rabin (1993) and Fehr and Schmidt (1999). The social-preference approach models people as caring about one another's material payoffs, whether positively or negatively. In these models (like in Rotemberg's), a consumer who feels unfairly treated by a firm might withhold demand to lower the firm's profits. In our model, by contrast, because customers simply do not savor unfairly

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[2]Rotemberg (2011) further explores the implications of fairness for pricing, focusing on other phenomena such as price discrimination.

priced goods, they withhold demand irrespective of whether it harms the firm. An advantage of our approach, which appears clearly in our macroeconomic application, is that fairness continues to matter in general equilibrium. This is not the case with many social preferences: Dufwenberg et al. (2011) show that when people's utility can be written as a separable function of their own and other people's allocations, social preferences do not affect Walrasian-equilibrium prices or allocations. For example, consider a model in which consumers disdain profit-making, but have preferences over their own consumption goods that do not vary with the level of profits. When they take prices and others' allocations as given, as in Walrasian equilibrium, consumers have no incentive to distort their consumption away from that affordable bundle which maximizes their preferences over their own consumption; intuitively, as much as a consumer might dislike that a firm earns high profits, she can do little in a large market to prevent it. Sobel (2007) shows that the same conclusion applies even when consumers have some market power.

Our assumption of subproportional inference shares some similarities with models of failures of contingent thinking. The game-theoretic concepts of cursed equilibrium developed by Eyster and Rabin (2005) and analogy-based-expectations developed by Jehiel and Koessler (2008) propose mechanisms through which people may fail to account for the information that equilibrium prices reveal about marginal costs. Customers in our model are also "coarse thinkers" in the sense of Mullainathan, Schwartzstein, and Shleifer (2008) because they do not distinguish between scenarios where changes in price reflect changes in cost and those where they reflect changes in markup. Subproportional inference also could be a form of the "anchoring heuristic" documented by Tversky and Kahneman (1974): consumers understand that higher prices reflect higher marginal costs but they do not adjust sufficiently their estimate of the marginal cost. It might also embody a form of the "availability heuristic" documented by Tversky and Kahneman (1973) and formalized by Gennaioli and Shleifer (2010): people infer information content by drawing upon a limited set of scenarios that come to mind. Higher prices suggest increased markups and greed, rather than higher marginal costs. Whereas we regard households' failure to infer marginal costs as a cognitive error, it might also result from economizing on attention costs along the lines proposed by Gabaix (2014). Lastly, the notion that to the extent that they infer about marginal costs, consumers assume a fixed proportional markup, is similar to the model of proportional thinking developed by Bushong, Rabin, and Schwartzstein (2017).

2. Evidence

We present empirical evidence regarding the assumptions that underlie our pricing theory. First, we show that people care about the fairness of prices, and that they assess a price to be fair when

it carries a low markup over marginal cost. Second, we document that people misinfer marginal costs from prices and thus systematically misperceive markups. Finally, we provide evidence that firms account for customers' fairness concerns when they set prices.

2.1. Customers' Concern for Fairness

To model fairness, we will assume that people deem a price to be fair when it entails a low markup over marginal costs. Religious and legal texts written over the ages suggest a long history of norms regarding markups. For example, Talmudic law specifies that the highest fair and allowable markup when trading essential items is 20% of the production cost, or one-sixth of the final price (Friedman 1984, p. 198). Another example comes from 18th-century France, where local authorities fixed bread prices by publishing "fair" prices in official decrees. In the city of Rouen, for instance, the official bread prices took the costs of grain, rent, milling, wood, and labor into account, and granted a "modest profit" to the baker (Miller 1999, p. 36). Thus, officials fixed the markup that bakers could charge. Even today, French bakers attach such importance to convincing their customers of fair markups that their trade union decomposes the cost of bread and the rationale for any price rise into minute detail (https://perma.cc/GQ28-JMFC). Two more examples come from regulation in the United States. First, return-on-cost regulation for public utilities—which limits the markups charged by utilities—has been justified not only on efficiency grounds but also on fairness grounds (for example, Zajac 1985; Jones and Mann 2001). Second, most US states have anti-price-gouging legislation that limits the prices that firms can charge in periods of upheaval (for example, a hurricane). But by exempting price increases based on cost, this legislation only outlaws price increases based on markups (Rotemberg 2009, pp. 74–77).

Our assumption that people find high markups unfair implies that they will find price increases unjustified by cost increases to be unfair. In a survey of Canadian residents, Kahneman, Knetsch, and Thaler (1986) document this pattern. They describe the following situation: "A hardware store has been selling snow shovels for $15. The morning after a large snowstorm, the store raises the price to $20." Among 107 respondents, only 18% regard this pricing as acceptable, whereas 82% regard it as unfair (p. 729). Conversely, our fairness assumption suggests that customers tolerate price increases following cost increases so long as the markup remains constant. Kahneman, Knetsch, and Thaler also identify this pattern: "Suppose that, due to a transportation mixup, there is a local shortage of lettuce and the wholesale price has increased. A local grocer has bought the usual quantity of lettuce at a price that is 30 cents per head higher than normal. The grocer raises the price of lettuce to customers by 30 cents per head." Among 101 respondents, 79% regard the pricing as acceptable, and only 21% find it unfair (pp. 732–733).

Subsequent studies confirm and refine Kahneman, Knetsch, and Thaler's results. For example,

in a survey of 1,750 households in Switzerland and Germany, Frey and Pommerehne (1993, pp. 297–298) confirm that customers dislike a price increase that involves an increase in markup; so too do Shiller, Boycko, and Korobov (1991, p. 389) in a comparative survey of 391 respondents in Russia and 361 in the United States. Using an online survey of 307 Dutch individuals, Gielissen, Dutilh, and Graafland (2008, table 2) substantiate that price increases that follow cost increases are fair, whereas those that follow demand increases are not. One natural concern about the snow-shovel-vignette evidence is that people may find the price increase unfair simply because it occurs during a period of hardship. To address this question, Maxwell (1995) ask 72 students at a Florida university about price increases following an ordinary increase in demand as well as those following a hardship-driven increase in demand. While fewer find price increases in the former environment than in the latter environment unfair (69% versus 86%), a substantial majority in each case perceive the price increase as unfair.

In our model, customers deem it equally unfair for firms not to pass along cost decreases. The evidence on this assumption is weaker. Kahneman, Knetsch, and Thaler describe the following situation: "A small factory produces tables and sells all that it can make at $200 each. Because of changes in the price of materials, the cost of making each table has recently decreased by $20. The factory does not change its price of tables." Only 47% of respondents find this unfair, despite the elevated markup (p. 734). However, subsequent studies challenge this finding by suggesting that people do expect the price to fall after a cost reduction. For instance, Kalapurakal, Dickson, and Urbany (1991) conduct a survey of 189 business students in the United States, and asked them to consider the following scenario: "A department store has been buying an oriental floor rug for $100. The standard pricing practice used by department stores is to price floor rugs at double their cost so the selling price of the rug is $200. This covers all the selling costs, overheads and includes profit. The department store can sell all of the rugs that it can buy. Suppose because of exchange rate changes the cost of the rug rises from $100 to $120 and the selling price is increased to $220. As a result of another change in currency exchange rates, the cost of the rug falls by $20 back to $100." Then two alternative scenarios were evaluated: "The department store continues to sell the rug for $220" compared to "The department store reduces the price of the rug to $200." The scenario in which the department store reduces the price in response to the decrease in cost was considered significantly more fair: the fairness rating was +2.3 instead of −0.4 (where −3 is extremely unfair and +3 extremely fair). Similarly, using a survey with US respondents, Konow (2001, table 6) finds that if a factory that sells a table at $150 suddenly locates a supplier charging $20 less for materials, then the average new fair price is $138, well below $150.[3]

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[3] Firms whose customers appraise prices relative to marginal costs have less incentive to cut marginal costs. In a survey of 1,530 cable-car customers in Switzerland, Bieger, Engeler, and Laesser (2010, table 3) find that while an external, uncontrollable cost increase (for instance, from increased security requirements) is perceived as a fair

Finally, we assume that customers who purchase a good at an unfair price derive less utility from consuming it; as a result, unfair pricing reduces customers' willingness to pay. Substantial evidence documents that unfair prices make customers angry, and more generally that unfair outcomes trigger feelings of anger (Rotemberg 2009, pp. 60–64). A small body of evidence suggests that customers indeed reduce purchases when they feel unfairly treated. In a telephone survey of 40 US consumers, Urbany, Madden, and Dickson (1989) explore—by looking at a 25-cent ATM surcharge—whether a price increase justified by a cost increase is perceived as more fair than an unjustified one, and whether fairness perceptions affect customers' propensity to buy. While 58% of respondents judge the introduction of the surcharge fair when justified by a cost increase, only 29% judge it fair when not justified (table 1, panel B). Moreover, those people who find the surcharge unfair are indeed more likely to switch banks (52% versus 35%, see table 1, panel C). Similarly, Piron and Fernandez (1995) present survey and laboratory evidence that customers who find a firm's actions unfair tend to reduce their purchases with that firm.

2.2. Subproportional Inference

Customers do not observe firms' marginal costs. Consequently, their perception of the fairness of firms' prices depends upon their estimates of marginal costs. If all customers in our model were rational, and firms understood this, then firms would set prices proportional to marginal cost, and consumers would rationally infer marginal costs proportional to price. We introduce two substantive departures from that rational benchmark. First, consumers underinfer marginal cost from price: they form beliefs that depend upon some anchor, which may be their prior expectation of marginal cost. Second, insofar as consumers do update their beliefs about marginal cost from price, they engage in a form of proportional thinking by estimating marginal costs that are proportional to price. We dub this pair of assumptions subproportional inference. Customers who update subproportionally recognize that higher prices signal higher marginal costs, but stop short of rational inference. Consequently, consumers overestimate markups when facing higher prices, and underestimate markups when facing lower prices.

Numerous experimental studies establish that people underinfer other people's information from those other people's actions. Samuelson and Bazerman (1985), Holt and Sherman (1994), Carillo and Palfrey (2011), and others provide evidence in the context of bilateral bargaining with asymmetric information that bargainers underappreciate the adverse selection in trade. The papers collected in Kagel and Levin (2002) present evidence that bidders underattend to the winner's curse

reason to raise prices, an internal, controllable cost increase (for instance, from higher marketing expenditures) is perceived as a less fair reason for raising prices. Nevertheless, respondents find both types of price increase much fairer than an unexplained price increase.

in common-value auctions. In a meta-study of social-learning experiments, Weizsacker (2010) finds that subjects behave as if they underinfer their predecessors' private information from their actions. In a voting experiment, Esponda and Vespa (2014) show that people underinfer others' private information from their votes. Subproportional inference includes such underinference.

Additionally, Shafir, Diamond, and Tversky (1997) report survey evidence that points at underinference in the context of pricing. They presented 362 people in New Jersey with the following thought experiment: "Changes in the economy often have an effect on people's financial decisions. Imagine that the US experienced unusually high inflation which affected all sectors of the economy. Imagine that within a six-month period all benefits and salaries, as well as the prices of all goods and services, went up by approximately 25%. You now earn and spend 25% more than before. Six months ago, you were planning to buy a leather armchair whose price during the 6-month period went up from $400 to $500. Would you be more or less likely to buy the armchair now?" The higher prices were distinctly aversive: while 55% of respondents were as likely to buy as before and 7% were more likely to buy as before, 38% of respondents were less likely to buy then before (p. 355). Our model makes this prediction because some consumers perceive markups to be higher when prices are higher. These consumers deem today's transaction less fair, so they have a lower willingness to pay for the armchair.

A survey conducted by Shiller (1997) confirms that when consumers see higher prices, they systematically believe that markups are higher. Among 120 respondents in the United States, 85% report that they dislike inflation because when they "go to the store and see that prices are higher," they "feel a little angry at someone" (p. 21). The most common perceived culprits are "manufacturers," "store owners," and "businesses," whose transgressions include "greed" and "corporate profits" (p. 25). In the presence of higher prices, many people infer that firms have increased their profit margins, which causes them anger.

In our model, customers dislike inflation because it leads them to perceive higher markups; symmetrically, they enjoy deflation because it leads them to perceive lower markups. An opinion poll conducted by the Bank of Japan between 2001 and 2017 paints this pattern (table 1). During this period, Japan alternated between inflation and deflation. Yet people hold diametrically opposed views toward inflation and deflation. Of the 18,000 respondents who perceived a decrease in the price of the goods they purchased, 43% saw it as a favorable development, while 22% saw it as an unfavorable development; but of the 68,000 respondents who perceived a price increase, only 3% saw it as a favorable development, while 84% saw it as an unfavorable development.

Finally, a small body of evidence documents that people think proportionally, even in settings that do not call for proportional thinking. Classic papers by Thaler (1980) and Tversky and Kahneman (1981) demonstrate that people's willingness to invest time in lowering the price of a

Table 1. Opinions about Price Movements in Japan, 2001–2017

Perceived price change	Number of respondents	Opinion about perceived price change		
		Favorable	Neutral	Unfavorable
Prices have gone down	18,257	43.0%	34.2%	21.9%
Prices have gone up	68,491	2.5%	13.0%	83.7%

Source: The 60 waves of the Opinion Survey on the General Public's Mindset and Behavior conducted by the Bank of Japan between September 2001 and December 2017. Although the survey is administered since 1993, survey results are available online only since 2001: the table is based on these online results. The survey was conducted nearly every quarter with a random sample of 4,000 adults living in Japan. The average response rate was 57.2%. Respondents answered the following question: "How do you think prices (defined as overall prices of goods and services you purchase) have changed compared with one year ago?" (question 10, 11, 12, or 13, depending on the survey). Respondents who answered "prices have gone down significantly" or "prices have gone down slightly" are described on the first row of the table. Respondents who answered "prices have gone up significantly" or "prices have gone up slightly" are described on the second row of the table. The rest of the respondents, who answered "prices have remained almost unchanged," do not feature in the table. Those who answered that prices had gone down then answered "How would you describe your opinion of the price decline?" (question 10, 11, 12, 13, or 15, depending on the survey). The third column gives the share of those respondents who answered "rather favorable," the fourth column the share who answered "neither favorable nor unfavorable," and the fifth column the share who answered "rather unfavorable." Those who answered that prices had gone up then answered "How would you describe your opinion of the price rise?" (question 10, 11, 12, or 13, depending on the survey, and only after June 2004). The third, fourth, and fifth column give the share of those respondents who answered "rather favorable," "neither favorable nor unfavorable," and "rather unfavorable." Detailed survey results are available at http://www.boj.or.jp/en/research/o_survey/index.htm/.

good by a fixed dollar amount depends negatively upon the good's price; rather than care about the absolute savings, people appear to care about the proportional savings. Bushong, Rabin, and Schwartzstein (2017) provide a model of such proportional thinking and provide more evidence that people use it across a number of domains.

2.3. Firms' Concern for Fairness

In our model, in response to their customers' concern for fairness, firms pay great attention to fairness when setting prices. This seems to hold true in the real world: firms identify fairness to be a major concern in price-setting. Following Blinder et al. (1998), researchers have surveyed more than 12,000 firms across developed economies about their pricing practices (table 2). The typical study asks managers to evaluate the relevance of different pricing theories from the economics literature to explain their own pricing, in particular price rigidity. Amongst the theories that the managers deem most important, some version of fairness invariably appears, often called "implicit contracts" and described as follows: "firms tacitly agree to stabilize prices, perhaps out of fairness to customers." Indeed, fairness appeals to firms more than any other theory, with a median rank of 1 and a mean rank of 1.9 (table 3). The second most popular explanation for price rigidity

Table 2. Description of Firm Surveys About Pricing

Survey	Country	Period	Number of firms
Blinder et al. (1998)	United States (US)	1990–1992	200
Hall, Walsh, and Yates (2000)	United Kingdom (GB)	1995	654
Apel, Friberg, and Hallsten (2005)	Sweden (SE)	2000	626
Nakagawa, Hattori, and Takagawa (2000)	Japan (JP)	2000	630
Amirault, Kwan, and Wilkinson (2006)	Canada (CA)	2002–2003	170
Kwapil, Baumgartner, and Scharler (2005)	Austria (AT)	2004	873
Aucremanne and Druant (2005)	Belgium (BE)	2004	1,979
Loupias and Ricart (2004)	France (FR)	2004	1,662
Lunnemann and Matha (2006)	Luxembourg (LU)	2004	367
Hoeberichts and Stokman (2006)	Netherlands (NL)	2004	1,246
Martins (2005)	Portugal (PT)	2004	1,370
Alvarez and Hernando (2005)	Spain (ES)	2004	2,008
Langbraaten, Nordbo, and Wulfsberg (2008)	Norway (NO)	2007	725
Olafsson, Petursdottir, and Vignisdottir (2011)	Iceland (IS)	2008	262

takes the form of nominal contracts—prices do not change because they are fixed by contracts: it has a median rank of 3 and a mean rank of 2.6. Two common macroeconomic theories of price rigidity—menu costs and information delays—do not resonate at all with firms, who rank them amongst the least popular theories, with mean and median ranks above 9.

Firms also understand that customers bristle at unfair markups. Blinder et al. (1998, pp. 153–157) find that 64% of firms say that customers do not tolerate price increases after demand increases, while 71% of firms say that customers do tolerate price increase after cost increases. Firms seem to agree that the norm for fair pricing revolves around a constant markup over marginal cost. Based on a survey of businessmen in the United Kingdom, Hall and Hitch (1939, p. 19) report that the "the 'right' price, the one which 'ought' to be charged" is widely perceived to be a markup (generally, 10%) over average cost. Okun (1975, p. 362) also observes in discussions with business people that "empirically, the typical standard of fairness involves cost-oriented pricing with a markup."

Finally, to better understand how firms incorporate fairness into their pricing decisions, we interviewed 31 bakers in France in 2007. The French bread market makes a good case study because the market is large, bakers set their prices freely, and French people care enormously about bread.[4] We sampled bakeries in cities and villages around Grenoble, Aix-en-Provence, Paimpol,

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[4]In 2005, bakeries employed 148,000 workers, for a yearly turnover of 3.2 billion euros (Fraichard 2006). Since 1978, French bakers have been free to set their own prices, except during the inflationary period 1979–1987 when price ceilings and growth caps were imposed. For centuries, bread prices caused major social upheaval in France. Miller (1999, p. 35) explains that before the French Revolution, "affordable bread prices underlay any hopes for urban tranquility." During the Flour War of 1775, mobs chanted "if the price of bread does not go down, we will

Table 3. Ranking of Pricing Theories Across Surveys

Theory	Country of survey														Overall rank	
	US	GB	SE	JP	CA	AT	BE	FR	LU	NL	PT	ES	NO	IS	Median	Mean
Implicit contracts	4	5	1	1	2	1	1	4	1	2	1	1	2	1	1	1.9
Nominal contracts	5	1	3	3	3	2	2	3	3	1	5	3	1	2	3	2.6
Coordination failure	1	3	4	1	5	5	5	2	9	4	2	2	3	4	3.5	3.6
Pricing points	8	4	7	4	–	10	13	8	10	7	11	6	4	5	7	7.5
Menu costs	6	11	11	7	10	7	15	10	13	8	10	7	6	6	9	9.1
Information delays	11	–	13	–	11	6	14	–	15	–	8	9	5	–	11	10.2

Notes: Survey respondents rated the relevance of several pricing theories in explaining price rigidity in their own firm. The table shows how common theories rank amongst the alternatives. Blinder et al. (1998, table 5.1) describes the theories as follows (with wording varying slightly across surveys): "implicit contracts" stands for "firms tacitly agree to stabilize prices, perhaps out of fairness to customers"; "nominal contracts" stands for "prices are fixed by contracts"; "coordination failure" stands for two closely related theories, which are investigated in separate surveys: "firms hold back on price changes, waiting for other firms to go first" and "the price is sticky because the company loses many customers when it is raised, but gains only a few new ones when the price is reduced" (which is labeled "kinked demand curve"); "pricing points" stands for "certain prices (like $9.99) have special psychological significance"; "menu costs" stands for "firms incur costs of changing prices"; "information delays" stands for two closely related theories, which are investigated in separate surveys: "hierarchical delays slow down decisions" and "the information used to review prices is available infrequently." The rankings of the theories are reported in table 5.2 in Blinder et al. (1998); table 3 in Hall, Walsh, and Yates (2000); table 4 in Apel, Friberg, and Hallsten (2005); chart 14 in Nakagawa, Hattori, and Takagawa (2000); table 8 in Amirault, Kwan, and Wilkinson (2006); table 5 in Kwapil, Baumgartner, and Scharler (2005); table 18 in Aucremanne and Druant (2005); table 6.1 in Loupias and Ricart (2004); table 8 in Lunnemann and Matha (2006); table 10 in Hoeberichts and Stokman (2006); table 4 in Martins (2005); table 5 in Alvarez and Hernando (2005); chart 26 in Langbraaten, Nordbo, and Wulfsberg (2008); and table 17 in Olafsson, Petursdottir, and Vignisdottir (2011).

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and Paris. Overall, the interviews show that bakers restrain price variations to preserve customer loyalty. Price adjustments are guided by norms of fairness to avoid antagonizing customers; in particular, cost-based pricing is widely used. Bakers raise the price of bread only in response to increases in the cost of flour (generally only at the end of harvest in September), utilities, or wages. Bakers also refuse to increase prices in response to increased demand. Several bakers explained that they do not change prices during weekends (when more people shop at bakeries), during the holiday absences of local competitors (when their demand and market power rise), or during the summer tourist season (again, when demand rises) because it would be unfair—and hence anger and drive away customers.

3.   Monopoly Model

We extend a simple model of monopoly pricing to include fairness concerns and subproportional inference, along the lines described in section 2. In this extended model, the markup charged by the monopoly is lower. Furthermore, the markup responds to marginal-cost shocks, generating some price rigidity: prices are not completely fixed, but they respond less than one-for-one to marginal costs. Last, we allow the monopoly to credibly disclose its cost, and we study how it sets its price and strategically reveals information about cost.

3.1.   Assumptions

A monopoly sells a good to a representative customer. The monopoly cannot price-discriminate, so each unit of the good sells at the same price P. The customer cares about fairness and appraises transactional fairness by assessing the markup charged by the monopoly. Since the customer does not observe the marginal cost of production, she needs to infer it from the price. We assume that the perceived marginal cost is given by a belief function $MC^p(P)$. For simplicity, we restrict $MC^p(P)$ to be deterministic. Having inferred the marginal cost, the customer deduces that the markup charged by the monopoly is

$$K^p(P) = \frac{P}{MC^p(P)}.$$

The perceived markup determines the fairness of the transaction through a fairness function $F(K^p) > 0$. The functions $MC^p(P)$ and $F(K^p)$ are both assumed to be continuously differentiable.

exterminate the king and the blood of the Bourbons"; following these riots, "under intense pressure from irate and nervous demonstrators, the young governor of Versailles had ceded and fixed the price 'in the King's name' at two sous per pound, the mythohistoric just price inscribed in the memory of the century" (Kaplan 1996, p. 12).

A customer who buys Y at price P experiences the fairness-adjusted consumption

$$Z = F(K^p(P))Y,$$

which enters a quasilinear utility function:

$$\frac{\epsilon}{\epsilon - 1} Z^{(\epsilon-1)/\epsilon} + M.$$

The variable M designates money balances, and the parameter $\epsilon > 1$ governs the concavity of the utility function. The customer also faces a budget constraint:

$$M + PY = I,$$

where $I > 0$ is income.[5] Then, given F and P, the customer chooses M and Y to maximize utility subject to the budget constraint.

Finally, the monopoly has constant marginal cost $MC > 0$. It chooses P and Y to maximize profits $(P - MC)Y$ subject to customers' demand for its good.

3.2. Customer and Monopoly Behavior

First, we determine customers' demand for the monopoly good. The customer chooses Y to maximize

$$\frac{\epsilon}{\epsilon - 1} (FY)^{(\epsilon-1)/\epsilon} + I - PY.$$

The first-order condition is

$$F^{(\epsilon-1)/\epsilon} Y^{-1/\epsilon} = P,$$

which yields the demand curve

$$(1) \qquad\qquad Y^d(P) = P^{-\epsilon} F(K^p(P))^{\epsilon-1}.$$

The price affects demand through two channels: the typical substitution effect, captured by $P^{-\epsilon}$; and the fairness channel, captured by $F(K^p(P))^{\epsilon-1}$. The fairness channel appears because the price influences the perceived markup and thus the fairness of the transaction, which in turn affects the marginal utility of consumption and consequently demand.

Then we determine the optimal price for the monopoly. The monopoly chooses P to maximize

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[5]In this static setup, money balances allow customers to spend their income on something else than the monopoly's production; in the dynamic model of section 4, customers instead save part of their income in bonds.

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$(P - MC) Y^d(P)$. The first-order condition is

$$Y + (P - MC) \frac{dY^d}{dP} = 0.$$

The price elasticity of demand, normalized to be positive, is

$$E = -\frac{d\ln(Y^d)}{d\ln(P)}.$$

The first-order condition then yields

(2)
$$P = \frac{E}{E - 1} MC.$$

Hence, the monopoly sets its price at a markup $K = E/(E - 1)$ over marginal cost.

To learn more about the monopoly's markup, we compute the elasticity E. Using (1), we find

(3)
$$E = \epsilon + (\epsilon - 1) \phi \left[1 - \frac{d\ln(MC^p)}{d\ln(P)} \right],$$

where

$$\phi = -\frac{d\ln(F)}{d\ln(K^p)}$$

is the elasticity of the fairness function with respect to the perceived markup, normalized to be positive. The first term, ϵ, describes the standard substitution effect. The second term, $(\epsilon - 1)\phi [1 - d\ln(MC^p)/d\ln(P)]$, represents the fairness channel and splits into two subterms. The first subterm, $(\epsilon - 1)\phi$, appears because a higher price mechanically raises the perceived markup and thus reduces fairness. The second subterm, $-(\epsilon - 1)\phi [d\ln(MC^p)/d\ln(P)]$, appears because a higher price conveys information about the marginal cost and thus influences perceived markup and fairness. We now use (3) to compute the monopoly's markup in various situations.

3.3.   No Fairness Concerns

Before studying the more realistic case with fairness concerns, we examine the benchmark case in which customers do not care about fairness.

DEFINITION 1: *Customers who do not care about fairness have a fairness function $F(K^p) = 1$.*

Without fairness concerns, the fairness function is constant, so its elasticity is $\phi = 0$. According to (3), the price elasticity of demand is therefore constant, equal to ϵ. This implies that the monopoly's markup takes a standard value of $\epsilon/(\epsilon - 1)$.

Since the markup is independent of marginal cost, changes in marginal cost are fully passed through into the price; that is, prices are flexible. Formally, the marginal-cost passthrough is

$$\sigma = \frac{d\ln(P)}{d\ln(MC)},$$

which measures the percentage change in price when the marginal cost increases by one percent. The passthrough takes the value of one because $P = \epsilon MC/(\epsilon - 1)$.

The following lemma summarizes the findings:

LEMMA 1: *When customers do not care about fairness, irrespective of the belief function $MC^p(P)$, the monopoly optimally sets the markup to $K = \epsilon/(\epsilon - 1)$, and the marginal-cost passthrough is $\sigma = 1$.*

3.4. Rational Inference

Before studying subproportional inference, we analyze another benchmark case in which customers care about fairness and rationally invert the price to uncover the hidden marginal cost. In this case, the model takes the form of a simple signaling game in which the monopoly learns its marginal cost and chooses a price, before customers observe the monopoly's price—but not its marginal cost—and formulate demand. Let $[0, MC^h] \subset \mathbb{R}_+$ be the set of all possible marginal costs for the monopoly. The monopoly knows its marginal cost $MC \in [0, MC^h]$, but customers do not; instead, customers have non-atomistic prior beliefs over $[0, MC^h]$.

We look for a Perfect Bayesian Equilibrium (PBE) of this game having the property that the monopoly chooses different prices for different marginal costs, which allows a rational customer who knows the monopoly's equilibrium strategy and observes the price to deduce marginal cost (separating equilibrium). A PBE comprises three elements: a pure strategy for the monopolist, which is a mapping $P : [0, MC^h] \to \mathbb{R}_+$ that selects a price for every possible value of marginal cost; a belief function for customers, which is a mapping $MC^p : \mathbb{R}_+ \to [0, MC^h]$ that determines a marginal cost for every possible price; and a pure strategy for customers, which is a mapping $Y^d : \mathbb{R}_+ \to \mathbb{R}_+$ that selects a quantity purchased for every possible price. We now show that there exists a PBE in which the monopolist's strategy is $P(MC) = \epsilon MC/(\epsilon - 1)$; customers' belief function is $MC^p(P) = (\epsilon - 1)P/\epsilon$ if

$$P \in \mathcal{P} \equiv \left[0, \frac{\epsilon}{\epsilon - 1} MC^h\right],$$

and $MC^p(P) = 0$ otherwise; and customers' strategy is $Y^d(P) = P^{-\epsilon}F(P/MC^p(P))^{\epsilon-1}$. In such PBE, customers correctly infer marginal costs from prices on the equilibrium path ($P \in \mathcal{P}$), and

they infer the worst when they observe a price off the equilibrium path ($P \notin \mathcal{P}$)—namely that the firm has zero marginal cost and thus infinitely high markup.

The argument proceeds in three steps. First, given their beliefs, customers' strategy is indeed optimal, as we have showed in (1). Second, given the monopolist's strategy, customers' beliefs are indeed correct for any price on the equilibrium path. Third, given customers' beliefs and strategy, the monopolist's strategy is optimal. Indeed, given customers' beliefs for $P \in \mathcal{P}$, we have $d\ln(MC^p)/d\ln(P) = 1$. Then, according to (3) (which is implied by customers' strategy), the price elasticity of demand for any price on $\mathcal{P}$ is $E = \epsilon$. Hence, (2) implies that it is optimal for the monopolist to charge a price $P = \epsilon MC/(\epsilon - 1)$. It remains to show that the monopoly has no incentive to charge some price not belonging to $\mathcal{P}$. This is straightforward: if it does, customers infer that the marginal cost is zero and the markup infinite, which brings fairness factor, demand, and thus profits to zero. Thus, the monopolist has no incentive to deviate from the equilibrium markup $\epsilon/(\epsilon - 1)$, regardless of its marginal cost.

The following lemma summarizes the findings:

LEMMA 2: *When customers rationally infer marginal costs, irrespective of the fairness function $F(K^p)$, there is a PBE in which the monopoly uses the markup $K = \epsilon/(\epsilon - 1)$, and customers learn marginal cost from price. In this PBE, the marginal-cost passthrough is $\sigma = 1$. Hence, in this PBE, the markup and passthrough are the same as without fairness concerns.*

Without fairness concerns, the price affects demand only by changing customers' budget sets. With fairness concern, the price affects demand through a second channel, by changing the perceived markup. However, following observation of any price chosen by the monopoly in equilibrium, customers perceive the same markup $\epsilon/(\epsilon - 1)$. The second channel closes, so the monopoly sets the standard markup. Since the markup does not depend on marginal cost, changes in marginal cost are fully passed through into prices—prices are flexible again.[6]

3.5. Fairness Concerns and Subproportional Inference

We turn to the case in which customers care about fairness and fall short of rational inference in two ways: they fail to fully appreciate how prices signal marginal costs, and insofar as they do infer marginal cost from price, customers perceive markups to be constant. To describe this case, we impose some structure on the fairness and belief functions.

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[6]If customers infer proportionally instead of rationally—they perceive $MC^p(P) = P/K^p$, with a wrong value of K^p—the results remain the same, and fairness plays no role. Here too, since $d\ln(MC^p)/d\ln(P) = 1$, equation (3) indicates that the price elasticity of demand is ϵ; therefore, the optimal markup is $\epsilon/(\epsilon - 1)$.

DEFINITION 2: *Customers who care about fairness have a fairness function $F(K^p)$ that is positive, strictly decreasing, and weakly concave on $[0, K^h]$, where $F(K^h) = 0$ and $K^h > \epsilon/(\epsilon - 1)$.*

The assumption that the fairness function strictly decreases in the perceived markup captures the patterns, seen in section 2, that customers find higher markups less fair and derive displeasure from unfair transactions. The assumption that the fairness function is weakly concave means that a discrete increase in perceived markup causes a utility loss of equal magnitude (if F is linear) or of greater magnitude (if F is strictly concave) than the utility gain caused by a equal-sized decrease in perceived markup. Despite not finding direct evidence on this assumption, we believe that people are at least as outraged over a price increase as they are happy about a price decrease of the same magnitude.

DEFINITION 3: *Customers who update subproportionally use the belief-updating rule*

$$(4) \qquad MC^p(P) = \left(MC^b\right)^\gamma \left(\frac{\epsilon - 1}{\epsilon} P\right)^{1-\gamma},$$

where

$$(5) \qquad MC^b > \frac{\epsilon - 1}{\epsilon} \left(K^h\right)^{-1/\gamma} MC,$$

is a prior point belief about marginal cost, and $\gamma \in (0, 1]$ governs the extent to which beliefs anchor on that prior belief.

Section 2 provides evidence that customers do not sufficiently introspect about the relationship between price and marginal cost, which leads them to underappreciate the information conveyed by the price; it also documents people's tendency to think proportionally. The updating rule (4) encompasses these two types of error by having the perceived marginal cost be a geometric average of some prior point belief about marginal cost, MC^b, and the proportional inference about marginal cost, $(\epsilon - 1)P/\epsilon$. In the most extreme situation, when $\gamma = 1$, customers do not update at all about marginal cost based on price; they naively maintain their prior expectation MC^b, irrespective of the price they observe. When $\gamma > 0$, customers do learn from the price, but not enough. Moreover, insofar as they do learn from price, they do so proportionally. The updating rule has the property that in the limit as $\gamma = 0$, customers infer rationally because firms do indeed find it rational to use proportional markups when facing rational customers. Last, we impose (5) such that the perceived markup falls below K^h when the firm prices at marginal cost; this is necessary for equilibrium existence.[7]

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[7]Eyster, Rabin, and Vayanos (2019) propose an alternative to rational-expectations equilibrium in which traders

With the belief-updating rule (4), customers perceive the monopoly's markup to be

$$(6) \qquad K^p(P) = \left(\frac{\epsilon}{\epsilon - 1}\right)^{1-\gamma} \left(\frac{P}{MC^b}\right)^{\gamma}.$$

Since $\gamma > 0$, the perceived markup is increasing in the observed price. Customers appreciate that higher prices signal higher marginal costs; but by underappreciating the strength of the relationship between price and marginal cost, customers partially misattribute higher prices to higher markups. Consequently, they regard higher prices as less fair. Furthermore, as the functions $K^p(P)$ and $F(K^p)$ are differentiable, customers enjoy an infinitesimal price reduction as much as they dislike an infinitesimal price increase: the demand curve faced by the monopoly has no kinks, unlike in pricing theories based on loss aversion (Heidhues and Koszegi 2008).

Combining (3) and (4), we find that the price elasticity of demand satisfies

$$(7) \qquad E = \epsilon + (\epsilon - 1)\gamma\,\phi(K^p).$$

We have seen that without fairness concerns ($\phi = 0$), or with rational inference ($\gamma = 0$), the price elasticity of demand is constant, equal to ϵ. That result changes here.

First, the elasticity $\phi(K^p)$ is not longer zero:

LEMMA 3: *When customers care about fairness, the elasticity of the fairness function, $\phi(K^p)$, is strictly positive and strictly increasing in K^p on $(0, K^h)$, with $\lim_{K^p \to 0} \phi(K^p) = 0$ and $\lim_{K^p \to K^h} \phi(K^p) = +\infty$. Thus, the elasticity of $\phi(K^p)$ is positive on $(0, K^h)$:*

$$\chi \equiv \frac{d\ln(\phi)}{d\ln(K^p)} > 0.$$

The proof follows from the definition of the elasticity ϕ and the properties of the fairness function F: $\phi(K^p) = -K^p F'(K^p)/F(K^p)$; $F(K^p) > 0$ and $F'(K^p) < 0$; $F(K^p)$ is decreasing in

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underinfer one another's private information from market prices. In a "cursed expectation equilibrium" of a static model in which traders endowed with private information trade a risky asset, each trader forms an expectation about the value of the asset equal to a geometric average of her expectation conditional upon her private signal alone and her expectation conditional upon both her private signal and the market price. Traders' expectations therefore take the form of a weighted average of "naive beliefs" and *correct* beliefs. The updating rule in this paper has one important difference and one important similarity to that solution concept. The two rules differ to the extent that consumers in our model average naive beliefs with a particular form of *incorrect beliefs* (proportional inference); in order to include rational updating as a limit case, we calibrate the updating rule to match correct equilibrium beliefs for the case in which all consumers are rational. We adopt this approach for its analytic tractability and suspect that the main qualitative results of the paper would go through if people averaged their prior expectation of marginal cost with rational expectations about marginal cost. The two rules share the similarity that neither one lends itself to interpretation as someone's beliefs given a simple wrong theory of how other people's actions depend upon their private information. The belief-updating rule in this paper lacks a ready interpretation as consumers holding some wrong theory as to how firms set prices as a function of their marginal costs.

K^p while $-F'(K^p)$ is increasing in K^p; and $\lim_{K^p \to K^h} F(K^p) = 0$. The result about χ follows immediately, since $\chi = K^p \phi'(K^p)/\phi(K^p)$, $\phi'(K^p) > 0$, and $\phi(K^p) > 0$.

As a result, since $\gamma > 0$, the price elasticity of demand is always greater than ϵ. Moreover, since $\phi(K^p)$ is increasing in K^p and $K^p(P)$ in P, the price elasticity of demand is increasing in P. These properties have implications for the markup charged by the monopoly.

PROPOSITION 1: *When customers care about fairness and update subproportionally, the monopoly's markup is implicitly defined by*

$$(8) \qquad K = 1 + \frac{1}{\epsilon - 1} \cdot \frac{1}{1 + \gamma \phi(K^p(K \cdot MC))},$$

which implies that $K \in (1, \epsilon/(\epsilon - 1))$. Furthermore, the marginal-cost passthrough is given by

$$(9) \qquad \sigma = 1 \left/ \left[1 + \frac{\gamma^2 \phi \chi}{(1 + \gamma \phi)(\epsilon + (\epsilon - 1)\gamma \phi)} \right] \right.,$$

which implies that $\sigma \in (0, 1)$. Hence, the markup is lower than without fairness concerns or with rational inference; and unlike without fairness concerns or with rational inference, the marginal-cost passthrough is incomplete.

The proof appears in appendix A, yet the intuition behind the qualitative results is simple. First, when customers care about fairness but underinfer marginal costs, they become more price-sensitive. Indeed, an increase in the price increases the opportunity cost of consumption—as in the case without fairness—and also increases the perceived markup, which reduces the marginal utility of consumption and therefore demand. This heightened price-sensitivity raises the price elasticity of demand above ϵ and drives the markup below $\epsilon/(\epsilon - 1)$.

Second, after an increase in marginal cost, the monopoly optimally lowers its markup. This occurs because customers underappreciate the increase in marginal cost that accompanies a higher price. Since the perceived markup increases, the price elasticity of demand increases. In response, the monopoly reduces its markup, which mitigates the price increase. Thus, our model generates incomplete passthrough of marginal cost into price—a mild form of price rigidity. Furthermore, customers err in believing that transactions are less fair when the marginal cost increases: transactions actually become more fair.

The result that prices do not fully respond to marginal-cost shocks accords with empirical evidence. First, using matched data on product-level prices and producers' unit labor cost for Sweden, Carlsson and Skans (2012) find a moderate passthrough of idiosyncratic marginal-cost changes into prices: about 0.3. Second, using production data for Indian manufacturing firms, De Loecker et al. (2016, table 7) find that following trade liberalization in India, marginal costs

fell significantly due to the import tariff liberalization, yet prices failed to fall in step: they estimate passthroughs between 0.3 and 0.4. Third, using production and cost data for Mexican manufacturing firms, Caselli, Chatterjee, and Woodland (2017, table 7) also find a moderate passthrough of idiosyncratic marginal-cost changes into prices: between 0.2 and 0.4.

In our model, price rigidity arises from a nonconstant price elasticity of demand, which creates variations in markups after shocks. In that respect, our model shares similarities to other models in which a variable price elasticity leads to price rigidity. In international economics, these models have long been used to explain the behavior of exchange rates and prices (for example, Dornbusch 1985; Bergin and Feenstra 2001; Atkeson and Burstein 2008). In macroeconomics, such models have been used to create real rigidities—in the sense of Ball and Romer (1990)—that amplify nominal rigidities (for example, Kimball 1995; Dotsey and King 2005; Eichenbaum and Fisher 2007). However, whereas many of these models make reduced-form assumptions (in the utility function or in the demand curve) to generate a nonconstant price elasticity of demand, our model provides a microfoundation for this property.

Last, fairness operates by reducing the markup below its standard level $\epsilon/(\epsilon - 1)$ and toward 1. As the market becomes perfectly competitive, the markup necessarily approaches 1, and prices become flexible (as seen in (8) and (9) when $\epsilon \to \infty$). This implies that in perfectly competitive markets, our theory of fairness has no effect.

To perform additional comparative statics, we introduce a simple fairness function that satisfies all the requirements from definition 2. The fairness function is

$$(10) \qquad F(K^p) = 1 - \xi \cdot \left(K^p - \frac{\epsilon}{\epsilon - 1} \right),$$

where $\xi > 0$ governs the intensity of fairness concerns: a higher ξ means that a consumer grows more upset when consuming an overpriced item and more content when consuming an underpriced item. The fairness function reaches 1 when the perceived markup equals $\epsilon/(\epsilon - 1)$, the no-fairness markup; then fairness-adjusted consumption coincides with consumption. When the perceived markup exceeds $\epsilon/(\epsilon - 1)$, the fairness function falls below one; and when the perceived markup lies below $\epsilon/(\epsilon - 1)$, the fairness function surpasses one.

Furthermore, in order to compare different industries or economies, we focus on a situation in which customers have acclimated to prices by coming to judge firms' equilibrium markups as acceptable: MC^b adjusts so $K^p = \epsilon/(\epsilon - 1)$ and $F = 1$. Acclimation is likely to occur eventually within any industry or economy, once customers have faced the same prices for a long time.[8] Once

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[8]As noted by Kahneman, Knetsch, and Thaler (1986, p. 730), "Psychological studies of adaption suggest that any stable state of affairs tends to become accepted eventually, at least in the sense that alternatives to it no longer come to mind. Terms of exchange that are initially seen as unfair may in time acquire the status of a reference transaction. . . .

customers have acclimated, the elasticities of the fairness function (10) simplify to $\phi = \xi\epsilon/(\epsilon - 1)$ and $\chi = 1 + \xi\epsilon/(\epsilon - 1)$, so (8) and (9) become

$$K = 1 + \frac{1}{(1 + \gamma\xi)\,\epsilon - 1}$$

$$\sigma = 1 \Big/ \left[1 + \frac{\gamma^2\xi\,[(1 + \xi)\,\epsilon - 1]}{(1 + \gamma\xi)\,(\epsilon - 1)\,[(1 + \gamma\xi)\,\epsilon - 1]} \right].$$

Then, after some simple algebra, we obtain the following lemma:

COROLLARY 1: *Assume that customers care about fairness according to the fairness function* (10)*, infer subproportionally, and are acclimated. Then the monopoly's markup decreases with the competitiveness of the market* (ϵ)*, concern for fairness* (ξ)*, and degree of underinference* (γ)*. Moreover, the marginal-cost passthrough increases with the competitiveness of the market, but decreases with the concern for fairness and degree of underinference.*

The corollary shows that the passthrough is smaller in less-competitive markets. This implies that prices are more rigid in less-competitive markets. This property echoes the finding by Carlton (1986) that prices are more rigid in more concentrated industries. It is also consistent with the finding by Amiti, Itskhoki, and Konings (2014) that firms with higher market power have a lower passthrough of marginal-cost shocks driven by exchange-rate fluctuations.

Another implication of the corollary is that higher fairness concerns lower passthroughs. This implies that prices are more rigid in fairness-oriented markets. This property could contribute to explain the finding by Kackmeister (2007) that retail prices were more rigid—they changed less frequently and by smaller amounts—in 1889–1891 than in 1997–1999. Kackmeister emphasizes that the relationship between retailers and customers is much less personal today.[9] This weakened personal relationship suggests that the retail sector is probably less fairness-oriented today than in the 19th century, which helps to explain, according to our theory, greater price flexibility today. The property that prices are more rigid in fairness-oriented markets could also contribute to explain the finding by Nakamura and Steinsson (2008, tables 2 and 8) that prices change less frequently and by smaller amounts in the service sector than in nonservice sectors. Indeed, in the service sector, relationships between buyers and sellers are abound to be more personal than in nonservice sectors, making fairness concerns more salient.

[People] adapt their views of fairness to the norms of actual behavior."

[9]Kackmeister (2007, p. 2008) notes that "In 1889–1891 retailing often occurred in small one- or two-person shops, retailers supplied credit to the customers, and retailers usually delivered the purchases to the customer's home at no extra charge. Today retailing occurs in large stores, a third party supplies credit, and the customer takes his own items home. These changes decrease both the business and personal relationship between the retailer and the customer."

3.6. Disclosure

We now explore behavior when the monopoly can credibly disclose its marginal cost at the same time as setting its price. We determine whether the firm optimally conceals or discloses, alongside calculating its optimal markup in each case. We denote all variables when the firm discloses costs with a subscript d, and all variables when the firm conceals costs with a subscript c.

As a preliminary step, we explore pricing when marginal costs are observable. In this case, customers correctly perceive marginal cost ($MC^p = MC$), so the perceived markup equals the true markup ($K^p = K$). From (3), we see that the price elasticity of demand is $E = \epsilon + (\epsilon - 1)\phi(K) > \epsilon$. Using this expression, we obtain the following lemma:

LEMMA 4: *When customers care about fairness and observe marginal costs, the markup is implicitly defined by*

$$(11) \qquad\qquad K = 1 + \frac{1}{\epsilon - 1} \cdot \frac{1}{1 + \phi(K)},$$

implying that $K \in (1, \epsilon/(\epsilon - 1))$, and the marginal-cost passthrough is $\sigma = 1$. Hence, the markup is lower than without fairness concerns, but the passthrough is identical.

Without fairness concerns, the price affects demand solely through customers' budget sets. With fairness concerns and observable marginal costs, the price also influences the perceived fairness of the transaction: when the price is high relative to marginal cost, customers deem the transaction to be less fair, which reduces the marginal utility from consuming the good and hence demand. Consequently, the monopoly's demand is more price elastic than without fairness concerns, which forces the monopoly to charge a lower markup. However, with fairness concerns and observable marginal costs as without fairness concerns, the markup does not depend on marginal cost. Since changes in marginal cost do not affect the markup, they are completely passed through into price: prices are flexible. In sum, the model with fairness concerns and observable cost is isomorphic to a model without fairness concerns but with a less concave utility (a higher ϵ).

The lemma predicts that when customers care about fairness but observe costs, the passthrough of marginal costs into prices is one; in contrast, the passthrough is strictly below one when costs are not observed. Renner and Tyran (2004) provide evidence broadly consistent with this result: in a laboratory experiment, they find that price rigidity after a cost shock is much more pronounced when costs are observable than when they are not. Kachelmeier, Limberg, and Schadewald (1991a,b) also find in laboratory experiments that disclosing information on marginal-cost variations hastens the convergence of prices relative to the convergence observed in

markets without disclosure.

Now consider what would happen if the monopolist had the option to credibly disclose its marginal cost. We begin with the benchmark case in which customers infer rationally. Unlike in typical disclosure games, the monopoly has two distinct methods of revealing its marginal cost: directly through disclosure, or indirectly through price. This additional richness does not prevent the famous full-disclosure result of Milgrom (1981) from holding in our setting, however:

LEMMA 5: *Assume that customers care about fairness and infer rationally. In every PBE of the disclosure game, the monopoly discloses any marginal cost higher than the lowest possible value, and it sets a markup K_d given by (11). Hence, $K_d \in (1, \epsilon/(\epsilon - 1))$, and the marginal-cost passthrough is $\sigma = 1$.*

The proof is in appendix A. If the monopoly were constrained to charge a fixed price, then all but the lowest-marginal-cost type would reveal by exactly the logic of Milgrom (1981): a firm with a high marginal cost wishes to avoid being confounded with lower-marginal-cost types, because that would increase perceived markup. Flexible prices add a layer of complication to the story, since the higher-marginal-cost type also can provide customers with information through price. However, equilibrium concealment of any marginal cost higher than the lowest possible one would induce lower-marginal-cost types to deviate from equilibrium by mimicking its behavior. Consequently, only the lowest-marginal-cost type can conceal in equilibrium.

We now turn to the case of interest: customers fail to infer rationally. Here customers can draw inference both from the decision to disclose or not and from the price; it is therefore difficult to describe an inference somewhere in-between the rational inference—based on price and disclosure decision—and the naive inference. To simplify, we assume that customers are fully naive so they do not infer anything from concealment: $\gamma = 1$ in (4), implying that $MC^p = MC^b$. Customers do understand any marginal cost explicitly disclosed, however.

When the firm discloses its marginal cost, the perceived marginal cost MC^p equals the true marginal cost MC, so by setting price P the firm earns profits

$$(12) \qquad V_d(MC, P) = (P - MC) Y^d(P) = (P - MC) P^\epsilon F\left(\frac{P}{MC}\right)^{\epsilon - 1}.$$

When the firm conceals its marginal cost, the perceived marginal cost MC^p equals the prior belief MC^b, so by setting price P the firm earns profits

$$(13) \qquad V_c(MC, P) = (P - MC) Y^d(P) = (P - MC) P^\epsilon F\left(\frac{P}{MC^b}\right)^{\epsilon - 1}.$$

Since for any MC and P, $V_d(MC, P) > V_c(MC, P)$ if and only if $MC > MC^b$, the firm optimally

discloses whenever $MC > MC^b$, and conceals when $MC < MC^b$. The markups chosen following disclosure and concealment are given by (11) and (8) with $\gamma = 1$, respectively.

The following proposition summarizes these results:

PROPOSITION 2: *Assume that customers care about fairness but infer nothing about marginal cost from concealment: $MC^p = MC^b$. The firm optimally conceals for $MC < MC^b$ and discloses for $MC > MC^b$. When concealing, the firm uses the markup K_c given by (8) with $\gamma = 1$. When disclosing, the firm uses the markup K_d given by (11).*
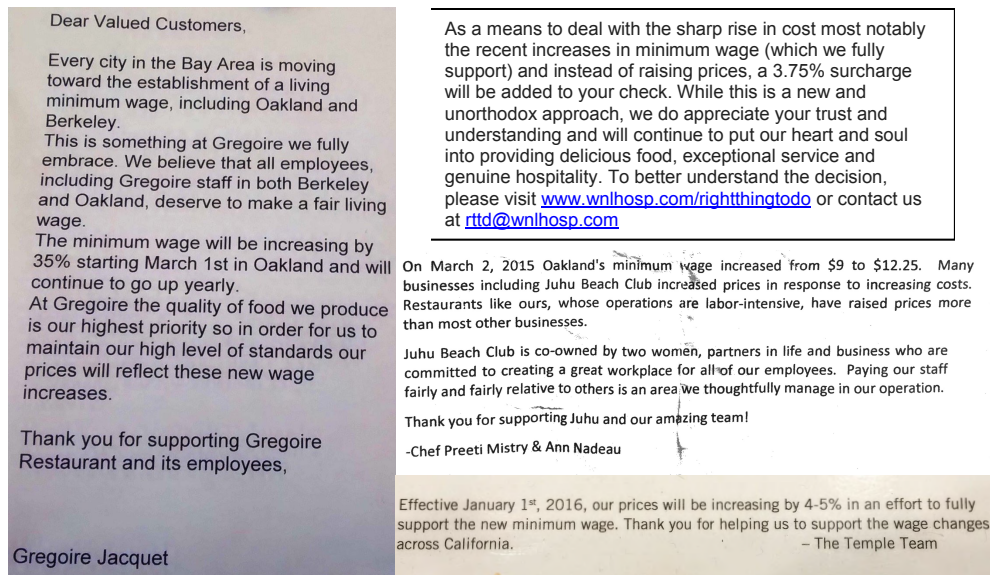
The rationale for the proposition is simple. Fixing the firm's price and marginal cost, its profits increase in its perceived marginal cost. When the firm conceals, its marginal cost is perceived as MC^b. A firm that has a marginal cost below this level wishes to conceal, whereas one with a higher marginal cost wishes to disclose.[10]

Proposition 2 can be interpreted as making a prediction about how a monopoly will respond to a cost shock. Suppose that MC^b is the monopolist's known marginal cost before it gets hit by a cost shock; the monopolist learns the realization of the shock, but customers do not. Proposition 2 implies that the firm will only disclose an increase in marginal cost, creating a a stark asymmetry between cost increases and decreases:
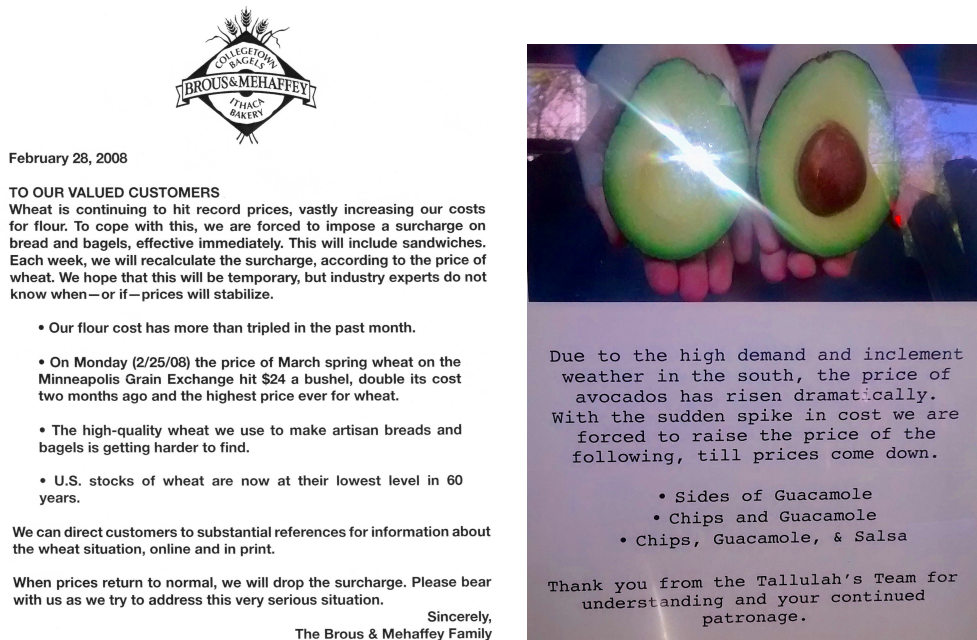
COROLLARY 2: *Assume that customers care about fairness but infer nothing about marginal cost from concealment: $MC^p = MC^b$. Suppose that the firm begins with marginal cost MC^b, which is known to customers, before being hit by a cost shock that is private information to the firm. Then prices are rigid downward but flexible upward. After a cost decrease, the firm conceals, so the passthrough is given by (9) with $\gamma = 1$, which is positive but strictly less than 1. After a cost increase, the firm discloses, so the passthrough is exactly 1.*

There is evidence consistent corollary 2: while we have never observed a firm advertise a decrease in production costs, we frequently observe firms advertising cost increases. Okun (1981, p. 153) observed that "In many industries, when firms raise their prices, they routinely issue announcements to their customers, insisting that higher costs have compelled them to do so." Figure 1, panel A, presents examples of firms disclosing their costs in response to a substantial increase in labor costs. The pictures were taken in restaurants in California after the large increases in minimum wage enacted there in 2015–2017. Many businesses responded to the minimum-wage increase by raising prices; many also felt compelled to explain why. Figure 1, panel B, shows that

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[10]Eyster and Rabin (2005) apply their game-theoretic equilibrium concept of "cursed equilibrium", in which each player in a Bayesian game underappreciates the relationship between other players' actions and those other players' private information, to a persuasion game. They identify a cursed equilibrium taking a similar threshold form—"bad types" conceal their types and "good types" reveal—based upon a similar logic.

Dear Valued Customers,

Every city in the Bay Area is moving toward the establishment of a living minimum wage, including Oakland and Berkeley.
This is something at Gregoire we fully embrace. We believe that all employees, including Gregoire staff in both Berkeley and Oakland, deserve to make a fair living wage.
The minimum wage will be increasing by 35% starting March 1st in Oakland and will continue to go up yearly.
At Gregoire the quality of food we produce is our highest priority so in order for us to maintain our high level of standards our prices will reflect these new wage increases.

Thank you for supporting Gregoire Restaurant and its employees,

Gregoire Jacquet

As a means to deal with the sharp rise in cost most notably the recent increases in minimum wage (which we fully support) and instead of raising prices, a 3.75% surcharge will be added to your check. While this is a new and unorthodox approach, we do appreciate your trust and understanding and will continue to put our heart and soul into providing delicious food, exceptional service and genuine hospitality. To better understand the decision, please visit www.wnlhosp.com/rightthingtodo or contact us at rttd@wnlhosp.com

On March 2, 2015 Oakland's minimum wage increased from $9 to $12.25. Many businesses including Juhu Beach Club increased prices in response to increasing costs. Restaurants like ours, whose operations are labor-intensive, have raised prices more than most other businesses.

Juhu Beach Club is co-owned by two women, partners in life and business who are committed to creating a great workplace for all of our employees. Paying our staff fairly and fairly relative to others is an area we thoughtfully manage in our operation.

Thank you for supporting Juhu and our amazing team!

-Chef Preeti Mistry & Ann Nadeau

Effective January 1st, 2016, our prices will be increasing by 4-5% in an effort to fully support the new minimum wage. Thank you for helping us to support the wage changes across California.   – The Temple Team

A. Large increases in minimum wage in California

BROUS & MEHAFFEY
ITHACA BAKERY
COLLEGETOWN BAGELS

February 28, 2008

TO OUR VALUED CUSTOMERS
Wheat is continuing to hit record prices, vastly increasing our costs for flour. To cope with this, we are forced to impose a surcharge on bread and bagels, effective immediately. This will include sandwiches. Each week, we will recalculate the surcharge, according to the price of wheat. We hope that this will be temporary, but industry experts do not know when—or if—prices will stabilize.

• Our flour cost has more than tripled in the past month.

• On Monday (2/25/08) the price of March spring wheat on the Minneapolis Grain Exchange hit $24 a bushel, double its cost two months ago and the highest price ever for wheat.

• The high-quality wheat we use to make artisan breads and bagels is getting harder to find.

• U.S. stocks of wheat are now at their lowest level in 60 years.

We can direct customers to substantial references for information about the wheat situation, online and in print.

When prices return to normal, we will drop the surcharge. Please bear with us as we try to address this very serious situation.

Sincerely,
The Brous & Mehaffey Family

Due to the high demand and inclement weather in the south, the price of avocados has risen dramatically. With the sudden spike in cost we are forced to raise the price of the following, till prices come down.

• Sides of Guacamole
• Chips and Guacamole
• Chips, Guacamole, & Salsa

Thank you from the Tallulah's Team for understanding and your continued patronage.

B. Large increases in commodity prices

Figure 1. Additional Examples of Firms Revealing Large Cost Increases

Sources: Panel A: pictures taken by Pascal Michaillat at restaurants across California between 2015 and 2017: Gregoire Restaurant in Berkeley, CA ; Prepkitchen in Del Mar, CA; Juhu Beach Club in Oakland, CA; Temple Coffee in Davis, CA. Panel B: left-side picture taken by Daniel Benjamin at Collegetown Bagels, Ithaca, NY, in 2008; right-side picture taken by Pascal Michaillat at Tallulah's Taqueria, Providence, RI in 2017.

firms go to great lengths to document large increases in the costs of raw material. In one picture, a bakery explains that an increase in wheat price translated into an increase in the price of flour, a key ingredient for bagels. To be more credible, the bakery also displayed next to the sign pictured here a graph from the *New York Times* plotting the prices of wheat over time.

Corollary 2 could also contribute to explain the finding by Peltzman (2000) that prices rise more after cost increases than they fall after cost decreases. Indeed, using US data on 77 consumer goods and 165 producer goods, Peltzman finds that on average, the price response to a cost increase is at least twice the price response to a cost decrease, and the difference lasts at least two quarters. The mechanism could also contribute to explain the asymmetric tax passthrough documented by Benzarti et al. (2017). Studying all changes to value-added taxes in Europe between 1996 and 2015, they find that the average price response to a tax increase is at least three times the response to a tax decrease; furthermore, the difference persists for several years.[11]

4. New Keynesian Model

Theories of price rigidity are a central element of modern macroeconomic models. To explore the macroeconomic implications of the pricing theory developed in section 3, we embed it into a textbook New Keynesian model, thus replacing Calvo pricing. We find that when customers care about fairness and infer subproportionally, the markup charged by monopolistic firms depends on the rate of inflation. As a result, monetary policy is nonneutral in the short run and in the long run.

4.1. Assumptions

The economy is composed of a continuum of households indexed by $j \in [0,1]$ and a continuum of firms indexed by $i \in [0,1]$. Households supply labor services, consume goods, and save using riskless nominal bonds. Firms use labor services to produce goods. Since the goods produced by firms are imperfect substitutes for one another, and the labor services supplied by households are also imperfect substitutes, each firm exercises some monopoly power on the goods market, and each household exercises some monopoly power on the labor market.

Fairness Concerns. We assume that each firm's marginal cost is unobservable to households. When a household purchases good i at price $P_i(t)$ in period t, it infers that firm i's marginal cost

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[11]From a monopoly's perspective, a change in value-added tax is equivalent to a change in marginal cost. With a value-added tax τ, there is a wedge between the post-tax price P and the pretax price $\hat{P} = P/(1+\tau)$. The monopoly's profits are $Y^d(P) \cdot (\hat{P} - MC) = Y^d(P) \cdot [P - (1+\tau)MC]/(1+\tau)$. Maximizing profits implies maximizing $Y^d(P) \cdot [P - (1+\tau)MC]$. Hence, with a value-added tax, the monopoly behaves as if there was no tax but the marginal cost was $(1+\tau)MC$. An change in tax is therefore tantamount to a change in marginal cost.

is $MC_i^p(t)$. Unlike in the static model, the dynamic model provides a natural candidate for the anchor that households use to infer marginal costs: last period's perception of marginal cost. Hence, instead of being given by (4) as in the static model, households' current perception of firm i's marginal cost evolves according to

$$(14) \qquad MC_i^p(t) = \left[MC_i^p(t-1)\right]^\gamma \left[\frac{\epsilon-1}{\epsilon}P_i(t)\right]^{1-\gamma},$$

where $MC_i^p(t-1)$ is last period's perception of the marginal cost.

Having inferred the marginal cost, the household deduces that the markup charged by firm i is $K_i^p(t) = P_i(t)/MC_i^p(t)$. This perceived markup determines the fairness of the transaction with firm i, measured by $F_i(K_i^p(t))$. The fairness function F_i, specific to good i, satisfies the conditions listed in definition 2. The elasticity of F_i with respect to K_i^p is $\phi_i = -d\ln(F_i)/d\ln(K_i^p)$.

An amount $Y_{ij}(t)$ of good i bought by household j at a unit price $P_i(t)$ yields a fairness-adjusted consumption $Z_{ij}(t) = F_i(K_i^p(P_i(t)))Y_{ij}(t)$. Household j's fairness-adjusted consumption of the different goods aggregates into a consumption index

$$(15) \qquad Z_j(t) = \left[\int_0^1 Z_{ij}(t)^{(\epsilon-1)/\epsilon}di\right]^{\epsilon/(\epsilon-1)},$$

where $\epsilon > 1$ is the elasticity of substitution between different goods. The price of one unit of the consumption index at time t is given by the price index

$$(16) \qquad X(t) = \left[\int_0^1 \left(\frac{P_i(t)}{F_i(K_i^p(P_i(t)))}\right)^{1-\epsilon}di\right]^{1/(1-\epsilon)}.$$

Households. Household j derives utility from consuming goods and disutility from working. Its utility at time 0 is

$$(17) \qquad \mathbb{E}_0 \sum_{t=0}^\infty \beta^t \left[\ln(Z_j(t)) - \frac{N_j(t)^{1+\eta}}{1+\eta}\right],$$

where $\mathbb{E}_0$ is expectation conditional on time-0 information, $N_j(t)$ is the amount of labor supplied, $\beta > 0$ is the time discount factor, and $\eta > 0$ is the inverse of the Frisch elasticity of labor supply.

Households also trade one-period bonds. Bonds purchased in period t have a price $Q(t)$, mature in period $t+1$, and pay one unit of money at maturity. In period t, household j holds $B_j(t)$ bonds.

Household j's budget constraint in period t is

$$(18) \qquad \int_0^1 P_i(t)Y_{ij}(t)di + Q(t)B_j(t) = W_j(t)N_j(t) + B_j(t-1) + V_j(t),$$

where $W_j(t)$ is the wage of labor service j and $V_j(t)$ are dividends from ownership of firms. In addition, household j is subject to a solvency constraint preventing Ponzi schemes: for all t, $\lim_{T\to\infty} \mathbb{E}_t[B_j(T)] \geq 0$.

Household j maximizes utility (17) by choosing sequences for the wage of labor service j, the amount of labor service j supplied, the amounts of goods consumed, and the amount of bonds held, $\{W_j(t), N_j(t), [Y_{ij}(t)]_{i=0}^1, B_j(t)\}_{t=0}^\infty$. The maximization is subject to the budget constraint (18), to the solvency condition, and to the constraint imposed by firms' demand for labor service j. The household takes as given its endowment of bonds, $B_j(-1)$, and the sequences for fairness factors, prices, and dividends, $\{[F_i(t)]_{i=0}^1, Q(t), [P_i(t)]_{i=0}^1, V_j(t)\}_{t=0}^\infty$.

Firms. Firm i hires labor to produce output using the production function

$$(19) \qquad Y_i(t) = A_i(t)N_i(t)^\alpha,$$

where $Y_i(t)$ is its output of good i, $A_i(t)$ is its technology level, $\alpha < 1$ is the extent of diminishing marginal returns to labor, and

$$(20) \qquad N_i(t) = \left[\int_0^1 N_{ij}(t)^{(\nu-1)/\nu}dj\right]^{\nu/(\nu-1)}$$

is an employment index. In the employment index, $N_{ij}(t)$ is the quantity of labor service j hired by firm i, and $\nu > 1$ is the elasticity of substitution between different labor services. The price of one unit of the employment index at time t is given by the wage index

$$(21) \qquad W(t) = \left[\int_0^1 W_j(t)^{1-\nu}dj\right]^{1/(1-\nu)}.$$

The level of technology $A_i(t)$ is exogenous, possibly stochastic, and is unobservable to households—making the firm's marginal cost unobservable.

Firm i chooses sequences for the price of good i, the output of good i, and the amounts of labor services employed, $\{P_i(t), Y_i(t), [N_{ij}(t)]_{j=0}^1\}_{t=0}^\infty$, to maximize the present-discounted value of

profits

$$(22) \qquad \mathbb{E}_0 \sum_{t=0}^{\infty} \Gamma(t) \left[P_i(t) Y_i(t) - \int_0^1 W_j(t) N_{ij}(t) dj \right],$$

where $\Gamma(t) = \beta^t [X(0)Z(0)]/[X(t)Z(t)]$ is the stochastic discount factor for nominal payoffs in period t. The maximization is subject to the production constraint (19), to the demand for good i, and to the law of motion of the perceived marginal cost, given by (14). The firm takes as given the initial belief about its marginal cost, $MC_i^p(-1)$, and the sequences for wages and discount factor, $\left\{ [W_j(t)]_{j=0}^1, \Gamma(t) \right\}_{t=0}^{\infty}$. The firm's profits are rebated to households as dividends.

Monetary Policy. We define the inflation rate between t and $t+1$ as $\pi(t+1) = \ln(P(t+1)/P(t))$, the nominal interest between t and $t+1$ as $i(t) = -\ln(Q(t))$, and the real interest rate as $r(t) = i(t) - \pi(t)$. The nominal interest rate is determined by monetary policy, following a simple rule:

$$(23) \qquad i(t) = i_0(t) + \mu\pi(t),$$

where $i_0(t)$ is exogenous and possibly stochastic, and $\mu > 0$ determines how the interest rate responds to inflation.

4.2. Household and Firm Behavior

We now describe the behavior of households and firms. The derivations are relegated to appendix B. Once this is done, we will be able to characterize the equilibrium. We will focus on symmetric equilibria: all households receive the same endowment and dividends; all firms share a common technology and face the same fairness and belief functions. As a result, all households behave the same, and all firms behave the same. In such an equilibrium, since all variables are the same for all households and for all firms, we will drop the subscripts i and j.

First, each household optimally allocates its consumption expenditure across all goods. Integrating over all households, we obtain the demand for good i:

$$(24) \qquad Y_i^d \left(t, P_i(t), MC_i^p(t-1) \right) = Z(t) \left[\frac{P_i(t)}{X(t)} \right]^{-\epsilon} F_i \left(\left[\frac{\epsilon}{\epsilon - 1} \right]^{1-\gamma} \left[\frac{P_i(t)}{MC_i^p(t-1)} \right]^{\gamma} \right)^{\epsilon-1},$$

where $Z(t) = \int_0^1 Z_j(t) dj$ describes the level of aggregate demand. The equation can be written as $Z_i^d \equiv F_i \cdot Y_i^d = Z \cdot [(P_i/F_i)/X]^{-\epsilon}$. As the price of one unit of Z_i is P_i/F_i and the price of one unit

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of Z is X, the relative price of Z_i is $(P_i/F_i)/X$. Hence, this alternative formulation says that the demand for Z_i equals aggregate demand Z times the relative price of Z_i to the power of $-\epsilon$. This is the standard expression for demand curves in this type of models.

Similarly, each firm optimally allocates its wage bill across all labor services. Integrating over all firms, we obtain the usual demand for labor service j:

$$(25) \qquad N_j^d(t, W_j(t)) = N(t) \left[\frac{W_j(t)}{W(t)} \right]^{-\nu},$$

where $N(t) = \int_0^1 N_i(t) di$ is aggregate employment.

Then, given labor demand (25), household j optimally sets its wage. In a a symmetric equilibrium, the optimal wage is given by

$$(26) \qquad \frac{W(t)}{P(t)} = \frac{\nu}{\nu - 1} N(t)^\eta Y(t).$$

As usual, the household sets its real wage at a markup of $\nu/(\nu - 1) > 1$ over its marginal rate of substitution between leisure and consumption.

Further, household j optimally smooths fairness-adjusted consumption over time. In a symmetric equilibrium, the household's consumption evolves according to the usual consumption Euler equation:

$$(27) \qquad Q(t) = \beta \mathbb{E}_t \left[\frac{P(t)Y(t)}{P(t+1)Y(t+1)} \right].$$

Next, firm i optimally sets its price. The price elasticity of the demand for good i, given by (24), is

$$(28) \qquad E_i(t) = -\frac{\partial \ln(Y_i^d)}{\partial \ln(P_i)} = \epsilon + (\epsilon - 1)\gamma \phi_i(K_i^p(t)).$$

This expression is the same as in the static model. Unlike in the static model, however, the profit-maximizing markup is not necessarily given by $E_i(t)/(E_i(t) - 1)$ because $E_i(t)$ does not capture the effect of $P_i(t)$ on future perceived marginal costs and thus future demand. Instead, the markup charged by firm i is determined a quasi elasticity $D_i(t) > 1$:

$$(29) \qquad K_i(t) = \frac{D_i(t)}{D_i(t) - 1}.$$

The gap between $D_i(t)$ and $E_i(t)$ indicates how much the price today affects perceived marginal

costs and thus demand in the future. We find that in a symmetric equilibrium, firms set prices such that

$$(30) \qquad \beta\mathbb{E}_t\left[\frac{E(t+1)-(1-\gamma)\epsilon}{D(t+1)}\right]+(1-\gamma\beta)=\frac{E(t)}{D(t)}.$$

This forward-looking equation gives the quasi elasticity $D(t)$ when prices are optimal, and thus the markup charged by firms.

Finally, in a symmetric equilibrium, all real variables are determined by the goods-market markup. First, the nominal marginal cost is the nominal wage divided by the marginal product of labor: $MC(t)=W(t)/\left(\alpha A(t)N(t)^{\alpha-1}\right)$. Using (19) and (26), we obtain the real marginal cost:

$$\frac{MC(t)}{P(t)}=\frac{\nu}{(\nu-1)\,\alpha}N(t)^{1+\eta}.$$

The real marginal cost is increasing in employment because the real wage increases with employment and the marginal product of labor falls with employment. Moreover the goods-market markup is the inverse of the real marginal cost: $K(t)=P(t)/MC(t)$. Thus, employment is decreasing in the goods-market markup:

$$(31) \qquad N(t)^{1+\eta}=\frac{(\nu-1)\,\alpha}{\nu}\cdot\frac{1}{K(t)}.$$

Then, employment determines output and real wage through (19) and (26).

4.3.   Equilibrium Dynamics

We now present the dynamical system describing a symmetric equilibrium. We denote the log of any variable $C(t)$ by $c(t)\equiv\ln(C(t))$, and the steady-state values of $C(t)$ and $c(t)$ by $\overline{C}$ and $\overline{c}$. For any variable $C(t)$ except the interest and inflation rates, we denote the log-deviation from steady state by $\widehat{c}(t)\equiv c(t)-\overline{c}$. For the interest and inflation rates, we denote the deviation (not log-deviation) from steady state by $\widehat{\pi}(t)\equiv\pi(t)-\overline{\pi}$, $\widehat{i_0}(t)\equiv i_0(t)-\overline{i_0}$, and $\widehat{r}(t)\equiv r(t)-\overline{r}$.

The first condition is the usual IS equation, obtained by combining the Euler equation (27) with the monetary-policy rule (23):

$$(32) \qquad \alpha\widehat{n}(t)+\mu\widehat{\pi}(t)=\alpha\mathbb{E}_t[\widehat{n}(t+1)]+\mathbb{E}_t[\widehat{\pi}(t+1)]-\widehat{i_0}(t)-\widehat{a}(t)+\mathbb{E}_t[\widehat{a}(t+1)].$$

The second equilibrium condition is the law of motion of the perceived markup, which derives

from the inference mechanism (14):

$$\widehat{k^p}(t) = \gamma \left[\widehat{\pi}(t) + \widehat{k^p}(t-1) \right].$$

(33)

This equation shows that the perceived markup today tends to be high if inflation is high or if the past perceived markup was high. Past beliefs matter because people use them as a basis for their current beliefs. Inflation matters because people do not fully appreciate the effect of inflation on nominal marginal costs.

The third condition is the short-run Phillips curve, obtained from pricing equation (30):

$$(1 - \beta\gamma)\widehat{k^p}(t) - \lambda_1 \widehat{n}(t) = \beta\gamma \mathbb{E}_t[\widehat{\pi}(t+1)] - \lambda_2 \mathbb{E}_t[\widehat{n}(t+1)],$$

(34)

where

$$\lambda_1 \equiv (1+\eta) \frac{\epsilon + (\epsilon-1)\gamma\overline{\phi}}{\gamma\overline{\phi}\,\overline{\chi}} \left[1 + \frac{(1-\beta)\gamma}{1-\beta\gamma}\overline{\phi} \right]$$

$$\lambda_2 \equiv (1+\eta)\beta \frac{\epsilon + (\epsilon-1)\overline{\phi}}{\overline{\phi}\,\overline{\chi}} \left[1 + \frac{(1-\beta)\gamma}{1-\beta\gamma}\overline{\phi} \right].$$

Using (33), we can write $\widehat{k^p}(t)$ as a function of past inflation rates:

$$\widehat{k^p}(t) = \sum_{i=0}^{\infty} \gamma^{i+1}\widehat{\pi}(t-i).$$

(35)

Combining this expression with the short-run Phillips curve offers an alternative formulation of the Phillips curve that highlights the presence of past inflation rates:

$$(1 - \beta\gamma)\sum_{i=0}^{\infty} \gamma^{i+1}\widehat{\pi}(t-i) - \lambda_1\widehat{n}(t) = \beta\gamma \mathbb{E}_t[\widehat{\pi}(t+1)] - \lambda_2 \mathbb{E}_t[\widehat{n}(t+1)].$$

The short-run Phillips curve relates inflation to employment. Beside current inflation and employment, the Phillips curve incorporates expectations of future inflation and employment, a typical feature of New Keynesian models (Gali 2008, p. 49). In addition, the Phillips curve includes past inflation rates. The lagged inflation terms appear in our Phillips curve because current perceived marginal costs, given by (14), depend on last period's perception of marginal costs. It follows that the current perception of the goods-market markup depends not only on current inflation but also on last period's perception of the markup; using the autoregressive structure of the perceived markup, we can express the perceived markup as a discounted sum of

lagged inflation terms (equation (35). These lagged terms are the ones in our Phillips curve.

The textbook New Keynesian Phillips curve is purely forward-looking. This is problematic because both lagged inflation and expected future inflation enter significantly in estimated New Keynesian Phillips curve (Mavroeidis, Plagborg-Moller, and Stock 2014, table 2). Our hybrid Phillips curve, involving both backward-looking and forward-looking elements, is therefore more realistic. Of course, there exist other variations of the textbook model that append backward-looking components to the Phillips curve. For example, Christiano, Eichenbaum, and Evans (2005) assume that the firms unable to reset their prices in a given period index their prices to past inflation; the Phillips curve resulting from this variation on Calvo pricing is also hybrid.[12]

Combining (33), (32), and (34), we obtain the system of difference equations characterizing the equilibrium:

$$
(36) \qquad \begin{bmatrix} \widehat{k^p}(t) \\ \mathbb{E}_t[\widehat{\pi}(t+1)] \\ \mathbb{E}_t[\widehat{n}(t+1)] \end{bmatrix} = \mathbf{A} \begin{bmatrix} \widehat{k^p}(t-1) \\ \widehat{\pi}(t) \\ \widehat{n}(t) \end{bmatrix} + \mathbf{B} \cdot \epsilon(t)
$$

where

$$
\mathbf{A} = \begin{bmatrix} \gamma & \gamma & 0 \\ \frac{(1-\beta\gamma)\alpha\gamma}{\lambda_2+\alpha\beta\gamma} & \frac{\lambda_2\mu+\alpha\gamma(1-\beta\gamma)}{\lambda_2+\alpha\beta\gamma} & \frac{(\lambda_2-\lambda_1)\alpha}{\lambda_2+\alpha\beta\gamma} \\ \frac{-(1-\beta\gamma)\gamma}{\lambda_2+\alpha\beta\gamma} & \frac{[\beta(\mu+\gamma)-1]\gamma}{\lambda_2+\alpha\beta\gamma} & \frac{\lambda_1+\alpha\beta\gamma}{\lambda_2+\alpha\beta\gamma} \end{bmatrix}, \quad \mathbf{B} = \begin{bmatrix} 0 \\ \frac{\lambda_2}{\lambda_2+\alpha\beta\gamma} \\ \frac{\beta\gamma}{\lambda_2+\alpha\beta\gamma} \end{bmatrix},
$$

and $\epsilon(t) \equiv \widehat{i_0}(t) + \widehat{a}(t) + \mathbb{E}_t[\widehat{a}(t+1)]$ is an exogenous shock realized at time t. This dynamical system determines employment $\widehat{n}(t)$, inflation $\widehat{\pi}(t)$, and perceived markup $\widehat{k^p}(t)$. We then obtain all the other variables from these three variables.

4.4. Calibration

We calibrate our model: for standard parameters, we use usual empirical evidence; for behavioral parameters, we use new evidence on the marginal-cost passthrough. The calibrated values of the parameters are summarized in table 4.

First, we specify a functional form for the fairness function: we use (10). This simple functional

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[12]The introduction of fairness concerns into the New Keynesian model improves the realism of the Phillips curve but leaves the IS equation unchanged. The IS equation is quite problematic, however. It is for instance the source of the many New Keynesian pathologies at the zero lower bound. Other behavioral elements have been introduced into the New Keynesian model to improve the IS equation. Michaillat and Saez (2018) develop a New Keynesian model in which wealth enters households' utility function. This assumption tilts the IS equation, eliminating the New Keynesian pathologies at the zero lower bound. Gabaix (2016) develops a New Keynesian model in which firms and households are inattentive to unusual events. This assumption modifies both the IS equation and Phillips curve, in a way that eliminates the New Keynesian pathologies at the zero lower bound and improves other aspects of the model.

form has two advantages. First, it introduces only one new parameter: ξ, which parameterizes the concern for fairness. Second, it is such that in a zero-inflation steady state (the case considered here), the fairness factor is just one. As shown by (14), in a zero-inflation steady state the perceived markup is $\overline{K^p} = \epsilon/(\epsilon - 1)$, so $\overline{F} = 1$. In steady state, customers are therefore acclimated: they are neither angry nor happy about markups. This seems like a desirable steady-state property.

We then calibrate the three parameters central to our theory: the fairness parameter ξ, the inference parameter γ, and the elasticity of substitution across goods ϵ. These parameters jointly determine the average goods-market markup and markup dynamics in response to shocks—which determine the dynamics of the marginal-cost passthrough. Hence, for the calibration, we match empirical evidence on markups and passthrough dynamics. We target the following three empirical moments: average goods-market markup, short-run marginal-cost passthrough, and long-run marginal-cost passthrough.

Using firm-level data, De Loecker and Eeckhout (2017) estimate the goods-market markup in the United States between 1950 and 2014. They find that the average markup hovers between 1.2 and 1.3 in the 1950–1980 period and rises from 1.2 to 1.7 in the 1980–2014 period. The average value of the markup since 2000 is about 1.5; we use this value as a first target.[13] Next, in the discussion of proposition 1, we showed that estimates of the short-run marginal-cost passthrough fall between 0.2 and 0.4; to be conservative, we target a short-run passthrough of 0.4. Last, Burstein and Gopinath (2014, table 7.4) estimate the dynamics of the exchange-rate passthrough in the United States and seven other countries. This passthrough measures the response of import prices to exchange-rate shocks; its level may not reflect the level of the marginal-cost passthrough because marginal costs may not vary one-for-one with exchange rates (Amiti, Itskhoki, and Konings 2014), but there is no reason for the exchange-rate and marginal-cost passthroughs to have different dynamics. On average, the immediate passthrough is estimated around 0.4 and the two-year passthrough around 0.7. Accordingly, we target a two-year passthrough of 0.7.[14]

We then take the perspective of one firm in our New Keynesian model, and simulate passthrough dynamics in response to an exogenous increase in the firm's marginal costs (see appendix B). We find that the fairness parameter ξ primarily affects the passthrough level while the inference

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[13]The aggregate markups computed by De Loecker and Eeckhout are commensurate to the markups estimated for specific industries or goods in the United States. In the automobile industry, Berry, Levinsohn, and Pakes (1995, p. 882) estimate that on average $(P - MC)/P = 0.239$, which translates into a markup of $K = P/MC = 1/(1 - 0.239) = 1.3$. In the ready-to-eat cereal industry, Nevo (2001, table 8) finds that a median estimate of $(P - MC)/P$ is 0.372, which translate into a markup of $K = P/MC = 1/(1 - 0.372) = 1.6$. In the coffee industry, Nakamura and Zerom (2010, table 6) also estimate a markup of 1.6. For most national-brand items retailed in supermarkets, Barsky et al. (2003, p. 166) discover that markups range between 1.4 and 2.1. Finally, earlier work surveyed by Rotemberg and Woodford (1995, pp. 261–266) also estimates similar markups: in marketing, the markup for a typical good is usually below 2; in industrial organization, markups are between 1.2 and 1.7.

[14]Estimating long-run passthroughs is challenging, which is why the empirical evidence is scarce.

Table 4. Parameter Values in Simulations

Value	Description	Source or target
	A. Common parameters	
$\beta = 0.99$	Quarterly discount factor	Annual rate of return = 4%
$\alpha = 1$	Marginal returns to labor	Labor share = 2/3
$\eta = 1.1$	Inverse of Frisch elasticity of labor supply	Chetty et al. (2013, table 2)
$\mu = 1.5$	Response of interest rate to inflation	Gali (2008, p. 52)
$\zeta = 3/4$	Persistence of interest-rate shock	Gali (2008, p. 52), Gali (2011, p. 26)
	B. Parameters of the New Keynesian model with fairness	
$\epsilon = 2.2$	Elasticity of substitution across goods	Steady-state markup = 1.5
$\xi = 9$	Fairness concern	Instantaneous passthrough = 0.4
$\gamma = 0.8$	Underinference	Two-year passthrough = 0.7
	C. Parameters of the textbook New Keynesian model	
$\epsilon = 3$	Elasticity of substitution across goods	Steady-state markup = 1.5
$\theta = 2/3$	Share of firms keeping price unchanged	Average price duration = 3 quarters

parameter γ primarily affects the passthrough dynamics. Based on the simulation, we set $\epsilon = 2.2$, $\xi = 9$, and $\gamma = 0.8$. With this calibration, we obtain a steady-state markup of 1.5, an instantaneous passthrough of 0.4, and a two-year passthrough of 0.7.

Next we calibrate the labor-supply parameter η, which governs the response of employment to shocks. We set $\eta = 1.1$, which gives a Frisch elasticity of labor supply of $1/1.1 = 0.9$. This value is the median microestimate of the Frisch elasticity for aggregate hours, which combines the labor-supply responses at the intensive and extensive margins (Chetty et al. 2013, table 2).

We then set the quarterly discount factor to $\beta = 0.99$, giving an annual rate of return on bonds of 4%. We also set the production-function parameter to $\alpha = 1$. This calibration guarantees that the labor share, which equals $\alpha/\overline{K}$ in steady state, takes its conventional value of 2/3.

Finally, we calibrate the monetary-policy rule by setting the response of the nominal interest rate to inflation to $\mu = 1.5$, which is consistent with observed variations in the federal funds rate since the 1980s (Gali 2008, p. 52).

In addition to our New Keynesian model, we calibrate a textbook New Keynesian model (described in appendix B). We will use the textbook model as a benchmark. For the parameters common to the two models, we use the same values—except for ϵ. In the textbook model, the steady-state markup is $\epsilon/(\epsilon - 1)$, so we set $\epsilon = 3$ to obtain a markup of 1.5. We also need to calibrate one parameter specific to the textbook model: θ. The textbook model uses Calvo pricing, and θ indicates the share of firms that cannot update their prices each period. We calibrate θ as in the literature: using microevidence on the frequency of price adjustments. If a share θ of firms keep their price fixed each period, the average duration of a price spell is $1/(1 - \theta)$ (Gali 2008,

p. 43). In the microdata underlying the US Consumer Price Index, the mean duration of price spells is about 3 quarters (Nakamura and Steinsson 2013, table 1). Hence, we set $1/(1 − \theta) = 3$, which implies $\theta = 2/3$.

4.5. Simulation

We study the response to an unexpected transitory shock to monetary policy. We focus on equilibrium dynamics around the zero-inflation steady state.[15] We assume that the exogenous component of the monetary-policy rule follows an AR(1) process:

$$\widehat{i_0}(t) = \zeta \, \widehat{i_0}(t − 1) + \epsilon^i(t)$$

where $\zeta \in (0, 1)$ governs the persistence of the shock and $\epsilon^i(t)$ is a white noise process with mean zero. A positive realization of ϵ^i is a contractionary monetary-policy shock, leading to a rise in the real interest rate. We set $\zeta = 3/4$, which corresponds to a moderate persistence (Gali 2008, p. 52; Gali 2011, p. 26).

Figure 2 displays the dynamic response to a contractionary monetary-policy shock comprising an increase of 25 basis point of ϵ^i at time 0. Without any response of inflation, this shock would lead to an increase of the annualized nominal interest rate by one percentage point. In the figure, the responses of the real interest rate and inflation are expressed in annual terms (by multiplying by 4 the responses of the variables $\widehat{\pi}(t)$ and $\widehat{r}(t)$). The responses of the other variables are expressed as percentage deviations from their steady-state values.

The tightening of monetary policy generates an increase in the real interest rate, and a decrease in inflation. Inflation is negative for about two quarters and close to zero after that. The deflation leads to a decrease in perceived goods-market markups, as customers underinfer the decrease in marginal costs from lower prices. Firms take advantage of lower perceived markups by raising their markups. The goods-market markup rises by more than 1%, and thus output and employment fall, by about 0.7%. (The responses of output and employment are the same since the production function is calibrated to be linear.)

As monetary-policy shocks influence output, employment, and other real variables, monetary policy is nonneutral. The nonneutrality of monetary policy is well documented: much of the evidence is summarized by Christiano, Eichenbaum, and Evans (1999) and Ramey (2016, sec. 3). Of course, many models of monetary nonneutrality have been developed (Blanchard 1990; Mankiw and Reis 2010), but, with the exception of Rotemberg (2005), none invoking fairness.

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[15]In our model it is simple to study equilibrium dynamics around steady states with positive or negative inflation. But in the textbook New Keynesian model, this is a complicated task (Coibion and Gorodnichenko 2011). To simplify the simulations of that model, we therefore follow the literature and concentrate on the zero-inflation steady state.
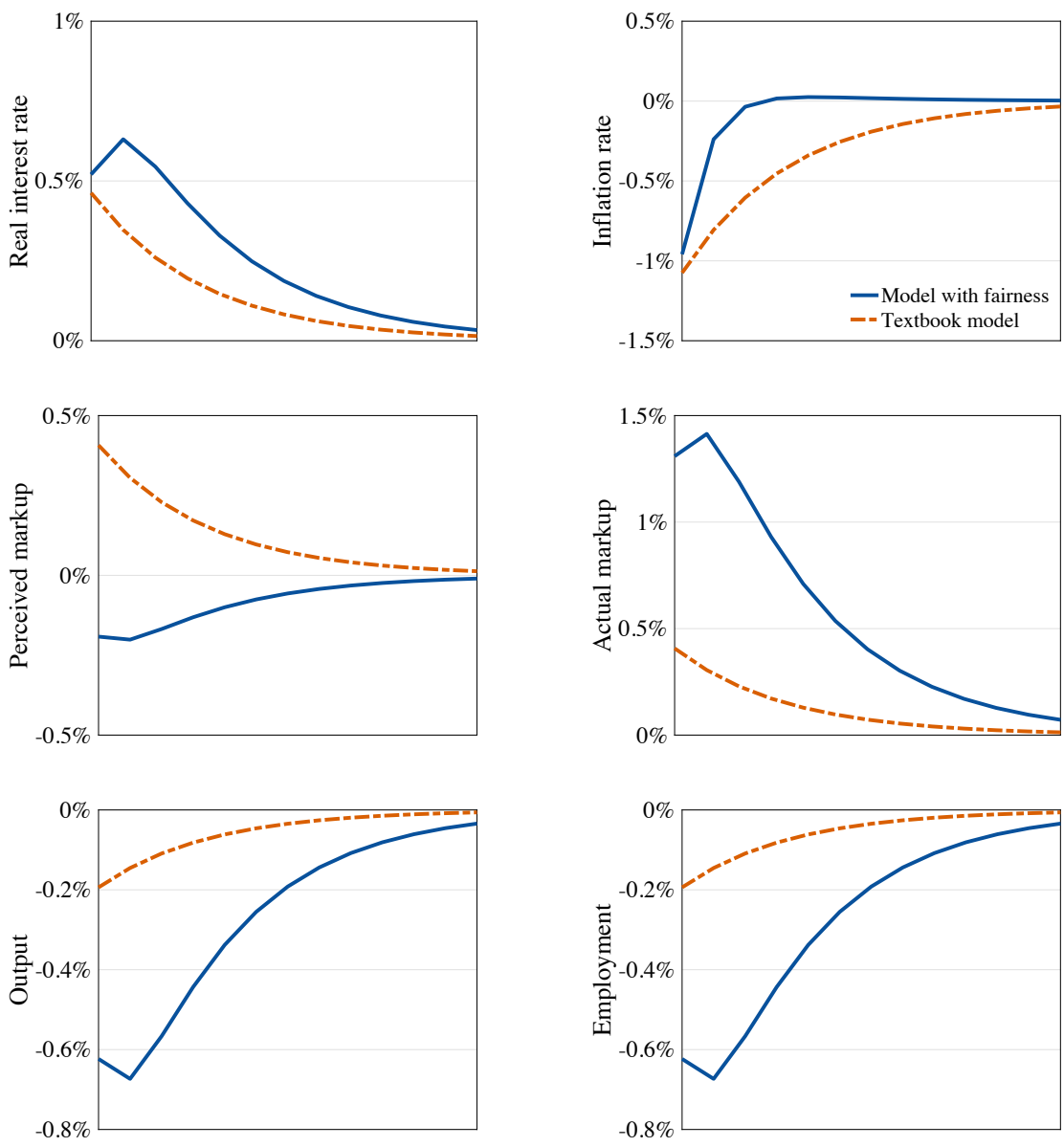
Figure 2. Response to Tighter Monetary Policy

Notes: This figure describes the response of the New Keynesian model with fairness (solid, blue lines) to an increase in the exogenous component of the monetary-policy rule, i_0, by one percentage point (annualized). The real interest rate and inflation rate are deviations from steady state, measured in percentage points and annualized. The other variables are percentage deviations from steady state. The model is described in section 4 and calibrated in table 4. For comparison, the figure also displays the response of the textbook New Keynesian model (dashed, orange lines). The textbook model is described in appendix B and calibrated in table 4.

In our New Keynesian model, as in the textbook model, the response of real variables to monetary-policy shocks is driven by the response of the goods-market markup. Here, the markup rises after an increase in nominal interest rate, which then drives lowers output and employment. If business cycles are generated by aggregate-demand shocks, then our model predicts that goods-market markups are countercyclical. There is indeed some evidence of countercyclical markups (for example, Rotemberg and Woodford 1999). Measuring aggregate markups is challenging, however, so the evidence is not definitive (see Nekarda and Ramey 2013).

There are several differences between the impulse responses of the model with fairness and those of the textbook model. The first is that the responses of output and employment are hump-shaped in the model with fairness but not in the textbook model. This property of the fairness model coincides with empirical evidence: output is estimated to respond to a monetary-policy shock in a hump-shaped fashion, peaking after several quarters (Ramey 2016, figs. 1–4). The responses are hump-shaped in the model with fairness because the dynamical system describing the equilibrium includes a backward-looking element, which is absent from the textbook model: the perceived markup $\widehat{k^p}(t)$, which enters the Phillips curve (34). It is well understood that backward-looking elements are important to obtain hump-shaped impulse responses. For example, in New Keynesian models, a typical way of obtaining hump-shaped responses is to assume that consumers form consumption habits (for example, Christiano, Eichenbaum, and Evans 2005). Under this assumption, developed by Fuhrer (2000), consumers' utility depends in part on current consumption relative to past consumption; therefore, past consumption enters the dynamical equilibrium system, generating hump-shaped response to monetary and other shocks.

The second difference concerns the response of the perceived markup. In the fairness model, households mistakenly believe that markups on the goods market are lower and transactions are more fair when they observe deflation. By contrast, in the textbook model, households correctly infer that markups on the goods market are higher when inflation is negative.

Hence, an advantage of our model is that it naturally explains why the Japanese customers surveyed by the Bank of Japan have a positive opinion of deflation and a negative opinion of inflation (table 1). Indeed, when there is deflation, people believe that markups are lower and transactions more fair, which raises their consumption utility, and triggers a feeling of happiness. In contrast, when there is inflation, people believe that markups are higher and transactions less fair, which reduces their consumption utility, and triggers a feeling of displeasure. By the same token, our model explains Shiller (1997)'s finding that people are angered by inflation. Yet, despite people's perceptions, markups are lower when monetary policy creates inflation and higher when it creates deflation, so loose monetary policy is indeed expansionary and tight monetary policy contractionary.

The third difference is that the response of the goods-market markup, employment, and output is about three times larger in the fairness model than in the textbook model. Thus, monetary shocks are more amplified in the fairness model—although both models are calibrated using microevidence on price dynamics. In fact the response of output to monetary policy in the fairness model is broadly consistent with available estimates for the United States. Ramey (2016, table 1) summarizes the literature: for an increase of the nominal interest rate by 1 percentage point, the estimated drop in output falls between 0.6% and 5%, with a median value of 1.6%. Ramey (2016, table 2) also conducts her own analysis using a range of methods and samples: the estimated drop in output is between 0.2% and 2.2%, with a median value of 0.8%. In our simulation, output falls by 0.7% when the exogenous component of the monetary-policy rule increases by 1 percentage point, quite close to Ramey's own estimates.

Finally, there is one important discrepancy between our model and the US evidence: the impulse response of inflation. In our model, the response of inflation to a monetary shock is immediate, and transient (inflation returns to zero after two quarters). The response of inflation is also immediate in the textbook model, but more persistent (inflation returns to zero after three years). On the contrary, in US data, the response of inflation to monetary shocks is delayed and gradual (Ramey 2016, figs. 1–4). It is not clear yet how this issue can be addressed.

4.6.   Monetary Policy in the Long Run

We study the long-run effects of monetary policy by comparing steady-state equilibria parameterized by different monetary-policy rules. In steady state, all real variables are constant and all nominal variables grow at a constant rate $\overline{\pi}$.

In steady state, the Euler equation (27) implies $\overline{i} = \rho + \overline{\pi}$, where $\rho = -\ln(\beta)$ is the time discount rate. Combining this equation with the monetary policy rule (23) implies that

$$(37) \qquad \overline{\pi} = \frac{\rho - \overline{i_0}}{\mu - 1}.$$

Hence, in the long run, monetary policy perfectly controls inflation: for instance, to obtain zero inflation, the exogenous component of the monetary-policy rule, $\overline{i_0}$, must be set to ρ; and, to obtain higher inflation, it suffices to reduce the exogenous component of the monetary-policy rule.

In turn, inflation determines the perceived goods-market markup:

$$(38) \qquad \overline{k^p}(\overline{\pi}) = \ln\left(\frac{\epsilon}{\epsilon - 1}\right) + \frac{\gamma}{1 - \gamma}\overline{\pi}.$$

This equation, obtained from (14), shows that households perceive higher markups when inflation

is higher. Households correctly adjust perceived marginal costs at the inflation rate (since perceived markups are constant in steady state), but because of subproportional inference, they misjudge the level of marginal costs.

Next, combining (28), (29), (30), and (38), we find that in steady state inflation determines the goods-market markup:

PROPOSITION 3: *The steady-state goods-market markup is a function of steady-state inflation:*

$$(39) \qquad \overline{K}(\overline{\pi}) = 1 + \frac{1}{\epsilon - 1} \cdot \frac{1}{1 + \frac{(1-\beta)\gamma}{1-\beta\gamma} \phi(\overline{k^p}(\overline{\pi}))}.$$

Hence the steady-state goods-market markup decreases with steady-state inflation.

Equation (39) is the counterpart to (8) in the monopoly model: the two equations have the same structure, so the two models operate fairly similarly. After an increase in inflation, households underappreciate the increase in nominal marginal costs, so they partly attribute the higher prices to higher markups, which they find unfair. Since perceived markups are higher, the price elasticities of the demands for goods increase, leading firms to reduce their markups.

Combining proposition 3 with equations (31) and (19), we link steady-state inflation to steady-state employment and output:

COROLLARY 3: *The long-run Phillips curve is upward sloping:*

$$(40) \qquad \overline{n} = \frac{1}{1 + \eta} \left[\ln(\alpha) - \ln\left(\frac{\nu}{\nu - 1}\right) - \overline{k}(\overline{\pi}) \right].$$

Thus, monetary policy is nonneutral in the long run: higher steady-state inflation leads to higher steady-state employment and output.

The main result of the corollary is that the long-run Phillips curve is not vertical but upward sloping, so monetary policy is nonneutral in the long run. The intuition is the following. As we saw previously, in the long run, higher inflation leads to lower markup on the goods market. In addition, in the long run, the goods-market markup determines employment. The markup is the inverse of the real marginal cost, which is the ratio of the real wage and the marginal product of labor. The real wage is proportional to the marginal rate of substitution between leisure and consumption, which is increasing in employment because the utility function is concave and because more employment means more consumption but less leisure. The marginal product of labor is decreasing in employment because of diminishing returns. Overall, in general equilibrium, the real marginal cost is increasing in employment. Since a lower markup implies a higher real marginal cost, a lower markup then yields higher employment.
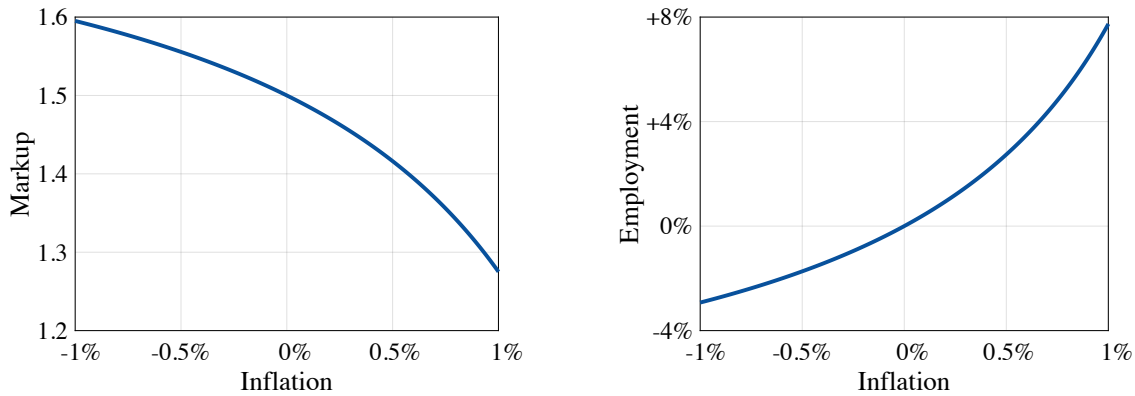
Figure 3. Long-Run Phillips Curves

Notes: The left-hand panel is one version of the long-run Phillips curve: it gives the relationship between steady-state inflation and steady-state goods-market markup. It is constructed using (39) under the calibration in table 4. The right-hand panel is another version of the long-run Phillips curve: it gives the relationship between steady-state inflation and steady-state employment. It is constructed using (40) under the calibration in table 4; on the y-axis, employment is measured as the percent deviation from the employment level with zero inflation.

The property higher steady-state inflation leads to higher steady-state employment is consistent with evidence that higher average inflation leads to lower average unemployment (for example, King and Watson 1994, 1997). There is also evidence that the mechanism behind the long-run Phillips curve—that higher inflation lowers markups on the goods market—operates. Benabou (1992) finds that in the US retail sector between 1948 and 1990, higher average inflation leads to lower average markup. Using aggregate US data covering 1953–2000, Banerjee and Russell (2005) also find that higher average inflation leads to lower average goods-market markup.

Our mechanism complements the traditional mechanism for an upward-sloping long-run Phillips curve: that because of downward nominal wage rigidity, steady-state inflation erodes real wages and thus reduces unemployment (Tobin 1972; Akerlof, Dickens, and Perry 1996; Benigno and Ricci 2011). While our mechanism operates on the goods market instead of the labor market, the psychological origin of the two mechanisms could be similar, since one possible source of wage rigidity is fairness concerns of workers.

To illustrate the magnitude of long-run nonneutrality, we compute the long-run Phillips curve for our calibrated model. Figure 3 displays two versions of the long-run Phillips curve: the first describes the relationship (39) between steady-state inflation and steady-state goods-market markup, and the second the relationship (40) between steady-state inflation and steady-state employment. When inflation raises from 0% to 1%, the markup falls from 1.5 to 1.3, and employment increases by 8%. On the other hand, if inflation falls from 0% to −1%, the markup rises from 1.5 to 1.6, and employment falls by 3%. This link between inflation and markup could explain part of the variation in markup measured by De Loecker and Eeckhout (2017) in the

United States between 1980 and 2014. They find that the average goods-market markup increased from 1.2 to 1.7 over that period. At the same time, average inflation fell from above 5% to around 1.5%. Through our mechanism, the drop in inflation could partly explain the increase in markup.[16]

5.   Conclusion

This paper develops a theory of pricing to fairness-minded customers. The theory revolves around two assumptions. First, customers derive more utility from a good priced at a low markup—perceived as fairly priced—than one priced at a high markup—perceived as unfairly priced. Second, customers attempting to work out markups—trying to discern hidden marginal costs from observed prices—infer subproportionally: they infer too little, and to the extent that they do infer, they misperceive markups as constant. These assumptions conform to common sense and copious evidence collected from customers and firms.

The main implication of the theory is price rigidity: the passthrough of marginal costs into prices is strictly less than one. When the theory is embedded into a New Keynesian model, price rigidity leads to the nonneutrality of monetary policy, both in the short run and in the long run. Furthermore, we are able to calibrate our two psychological parameters—concern for fairness and degree of underinference—from microevidence, just as any other parameter of the New Keynesian model. Consumers' concern for fairness is the only source of price rigidity in the model, so we calibrate it to match the short-run passthrough of marginal costs into prices that is estimated in microdata from a range of marginal-cost shocks. And since the degree of underinference determines how quickly customers learn about marginal costs, and thus how quickly firms adjust their prices, we calibrate the degree of underinference to match estimates of the long-run marginal-cost passthrough. When we simulate our calibrated New Keynesian model, we obtain realistic impulse responses of output and employment to monetary-policy shocks: the impulse responses are hump-shaped and have the appropriate amplitude.

The paper also clarifies the contexts in which fairness is likely to matter. First, hidden information and underinference seem important for fairness to operate. When costs are observable, or when costs are hidden but customers infer them rationally from prices, our model with fairness is isomorphic to a model without fairness. Only when costs are hidden and customers infer

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[16]The effect of inflation on employment and markup in figure 3 is quite large. If households acclimated at least partially to their beliefs about markups in each steady state, the theoretical results in proposition 3 and corollary 3 would remain valid, but the effects would be smaller. For instance, assume that the fairness function is given by $F(K^p) = 1 - \xi \cdot (K^P - \overline{K^P})$ instead of (10). Under this specification, the fairness factor is 1 when the perceived markup reaches its steady-state level, $\overline{K^P}$, not when it reaches $\epsilon/(\epsilon - 1)$. Thus, in steady state, the fairness factor is always 1, and the elasticity of the fairness function is $\phi(\overline{K^P}) = \xi \overline{K^P}$. As a result, the elasticity ϕ varies less across steady states, so steady-state inflation will have less impact.

subproportionally does fairness affect the qualitative properties of equilibrium, such as by creating price rigidity. Second, the model proposes a channel through which fairness concerns may matter in large markets, which is not the case for many common approaches to fairness (Dufwenberg et al. 2011; Sobel 2007). Indeed, because the fairness factor modifies the price elasticity of the demand curves in our model, fairness continues to matter in large markets—for instance, in our New Keynesian model.

One potentially fruitful application of our theory is the study of optimal monetary policy. Most models currently used to study optimal monetary policy rely on the assumption of infrequent pricing from Calvo (1983). Yet the Calvo model does not explain why firms should change prices only infrequently. Other models that provide rationales for the infrequency of firms' price changes have been less popular than the Calvo model because they lack its tractability. By contrast, our model is about as simple as the Calvo model, and has the feature that its microfoundations capture well—although perhaps a bit coarsely—the views of real-world customers and firms. Better microfoundations should make for a better analysis of monetary policy.

Before drawing conclusions about optimal monetary policy, however, it seems important to add to our macroeconomic model several channels through which inflation may also affect welfare. In the current model, inflation affects welfare through two goods-market channels: higher inflation reduces goods-market markups, thus increasing economic efficiency and welfare; and higher inflation induces a misperception that higher prices reflect higher goods-market markups, thus lowering perceived fairness and welfare. In reality, inflation may also affect welfare through several labor-market channels. First, as Akerlof, Dickens, and Perry (1996) proposed, moderate inflation erodes real wages if nominal wages are somewhat rigid, which leads to lower unemployment. Since unemployed workers suffer low well-being (Landais, Michaillat, and Saez 2018, pp. 193–195), higher inflation could improve welfare through this channel. Second, people seem to fear that rising prices will outpace wages, and that inflation will impoverish them (Shiller 1997). Through this channel, higher inflation may impose an additional psychological cost on consumers.

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Appendix A.   Proofs

Proof of Proposition 1

Since customers care about fairness and infer subproportionally, the price elasticity of demand, $E(K^p)$, is given by (7). Then, (2) indicates that the monopoly's optimal markup is given by

$$(A1) \qquad\qquad K = \frac{E(K^p)}{E(K^p) - 1}.$$

Equation (8) is obtained by combining (A1) with (7).

Toward showing that (8) admits a unique solution, we introduce

$$P^b = \frac{\epsilon}{\epsilon - 1}(K^h)^{1/\gamma} MC^b \qquad \text{and} \qquad K^b = \frac{P^b}{MC}.$$

The price P^b is defined such that if the firm sets a price P^b, the perceived markup reaches the upper bound of the domain of the fairness function: $K^p(P^b) = K^h$. Since MC^b satisfies (5), we have $P^b > MC$ and $K^b > 1$, which will ensure existence of the equilibrium.

We now prove that (8) admits a unique solution. Since $P = K \cdot MC$, P strictly increases from 0 to P^b when K increases from 0 to K^b. Next, (6) implies that $K^p(P)$ strictly increases from 0 to K^h when P increases from 0 to P^b. Last, lemma 3 indicates that $\phi(K^p)$ strictly increases from 0 to ∞ when K^p increases from 0 to K^h. As $\gamma > 0$, we conclude that when K increases from 0 to $K^b > 1$, the right-hand side of (8) strictly decreases from $\epsilon/(\epsilon - 1)$ to 1. Hence, (8) has a unique solution $K \in [0, K^b]$, implying that the equilibrium markup is well-defined and unique. Given the range of values taken by the right-hand side of (8), we also infer that $K \in (1, \epsilon/(\epsilon - 1))$.

Next we compute the marginal-cost passthrough, σ. The equilibrium price is given by $P = K(K^p(P)) \cdot MC$, where the monopoly's markup, $K(K^p)$, is given by (A1), and the perceived markup, $K^p(P)$, is given by (6). Using this price equation, we obtain

$$\sigma = \frac{d\ln(P)}{d\ln(MC)} = \frac{d\ln(K)}{d\ln(K^p)} \cdot \frac{d\ln(K^p)}{d\ln(P)} \cdot \frac{d\ln(P)}{d\ln(MC)} + 1.$$

Since $d\ln(K^p)/d\ln(P) = \gamma$ and $d\ln(P)/d\ln(MC) = \sigma$, the above equation yields

$$(A2) \qquad\qquad \sigma = \frac{1}{1 - \gamma \frac{d\ln(K)}{d\ln(K^p)}}.$$

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Then using (A1), we express the elasticity of $K(K^p)$ as a function of the elasticity of $E(K^p)$:

$$\frac{d\ln(K)}{d\ln(K^p)} = \left(1 - \frac{E}{E-1}\right)\frac{d\ln(E)}{d\ln(K^p)} = -\frac{1}{E-1} \cdot \frac{d\ln(E)}{d\ln(K^p)}.$$

Using (7), we express the elasticity of $E(K^p)$ as a function of the elasticity of $\phi(K^p)$, denoted χ:

$$\frac{d\ln(E)}{d\ln(K^p)} = \frac{E-\epsilon}{E} \cdot \frac{d\ln(\phi)}{d\ln(K^p)} = \frac{(E-\epsilon)\chi}{E}.$$

Combining the last two equations, and using the expression for $E(K^p)$ given by (7), we obtain

$$-\frac{d\ln(K)}{d\ln(K^p)} = \frac{(E-\epsilon)\chi}{(E-1)E} = \frac{\gamma\phi\chi}{[1+\gamma\phi][\epsilon+(\epsilon-1)\gamma\phi]}.$$

Combining this equation with (A2), we obtain (9). From (9), we infer that $\sigma \in (0,1)$ because $\gamma > 0$ (definition 3), $\phi > 0$ (lemma 3), and $\chi > 0$ (also lemma 3).

Proof of Lemma 5

Fix a PBE of the disclosure game. A PBE comprises three elements: a strategy for the monopolist, a belief mapping for customers, and a strategy for customers.

A strategy for the monopolist has three elements: one disclosure probability, which is a mapping $\sigma : [0, MC^h] \to [0,1]$ that gives the probability that a firm discloses its marginal cost for every possible value of marginal cost; and two price strategies, which are mappings $P_d : [0, MC^h] \to \mathbb{R}_+$ and $P_c : [0, MC^h] \to \mathbb{R}_+$ that select a price for every possible value of marginal cost when the firm discloses and conceals, respectively. We denote by $C = \{MC \in [0, MC^h] : \sigma(MC) > 0\}$ the set of types that conceal with positive probability.

The belief mapping for customers associates to every possible strategy by the monopolist a belief over possible marginal costs. If the monopolist discloses, irrespective of the price it sets, customers obviously know the marginal cost: $MC^p = MC$. If the monopolist conceals and sets a price P, customers form beliefs about the marginal cost of the firm; we denote by $B_P : [0, MC^h] \to [0,1]$ the cumulative distribution function of customers' beliefs about the marginal cost of a firm who conceals and chooses a price P.

Finally, a strategy for customers consists of a mapping $Y_d^d : \mathbb{R}_+ \to \mathbb{R}_+$ that selects a quantity purchased for every possible price when the firm discloses, and a mapping $Y_c^d : \mathbb{R}_+ \to \mathbb{R}_+$ that selects a quantity purchased for every possible price when the firm conceals.

We first derive the strategy of customers. If the monopoly discloses its marginal cost MC,

customers know the cost; therefore, using (1), we infer that customers' demand is

$$Y^d(MC, P) = P^{-\epsilon} F\left(\frac{P}{MC}\right)^{\epsilon-1}.$$

This is the same demand as when the monopoly's cost is observable. If the monopoly conceals and prices P, customers are uncertain about its marginal cost, so their expected utility is

$$\mathbb{E}_{B_P}\left[\left(F\left(\frac{P}{MC^p}\right) \cdot Y\right)^{(\epsilon-1)/\epsilon} + M\right],$$

which simplifies to

$$\mathbb{E}_{B_P}\left[F\left(\frac{P}{MC^p}\right)^{(\epsilon-1)/\epsilon}\right] Y^{(\epsilon-1)/\epsilon} + M.$$

Hence, at P, consumer demand is given by

$$Y^d(P) = P^{-\epsilon} \mathbb{E}_{B_P}\left[F\left(\frac{P}{MC^p}\right)^{(\epsilon-1)/\epsilon}\right]^{\epsilon}.$$

Next, we show that there cannot be a pooling equilibrium when firms conceal; that is, firms in C with distinct marginal costs charge distinct prices. Suppose instead that a subset $\mathcal{P}_0 \subset C$ of firms with distinct marginal costs charge the same price P_0. Now, because customers' priors are non-atomistic, the beliefs B_{P_0} are either non-atomistic over $\mathcal{P}_0$ or put atoms everywhere over $\mathcal{P}_0$. In either case, there must be at least one marginal cost $MC_0 \in \mathcal{P}_0$ which produces a value of F such that

$$Y_d^d(MC_0, P_0) = P_0^{-\epsilon}\left[F\left(\frac{P_0}{MC_0}\right)^{(\epsilon-1)/\epsilon}\right]^{\epsilon} > P_0^{-\epsilon} \mathbb{E}_{B_{P_0}}\left[F\left(\frac{P_0}{MC^p}\right)^{(\epsilon-1)/\epsilon}\right]^{\epsilon} = Y_c^d(P_0).$$

This means that type MC_0 would earn higher profits by disclosing its marginal cost without changing its price, a contradiction. Hence, no two types who conceal can charge the same price. This implies that the function P_c separates types on C, and thus that rational customers learn the marginal cost of any firm in C.

We then establish that when firms conceal, it is optimal for them to set the same price as when they disclose. The profits of type MC when disclosing and setting a price P and markup K are

(A3) $$V_d(MC, K) = (P - MC) Y_d^d(MC, P) = MC^{1-\epsilon} \cdot \frac{K-1}{(K)^{\epsilon}} \cdot F(K)^{\epsilon-1}.$$

When disclosing, the firm face the same problem as when marginal cost is observable, so it uses the markup K_d given by (11) and set a price $P_d(MC) = K_d\,MC$. The markup K_d satisfies $K_d = \arg\max_K V_d(MC,K)$. When the firm with marginal cost MC conceals, customers are nevertheless able to infer the firm's marginal cost in equilibrium. Hence, the firm's equilibrium profits when it conceals and sets a markup K are $V_c(MC,K) = V_d(MC,K)$. The equilibrium profits when a firm conceals must be at least as high as when a firm discloses, otherwise it would not be optimal to conceal. Since $V_c(MC,K) = V_d(MC,K)$, the equilibrium profits under concealment are uniquely maximized at the markup K_d, and the maximized equilibrium profits are $V_d(MC,K_d)$. Since a firm of type MC could disclose its marginal cost and earn such profit, the only way for a firm to earn at least as much when it conceals as when it discloses is to set a markup $K_c = K_d$, which can be achieved by charging a price $P_c(MC) = K_d\,MC$.

To conclude that only the lowest type can conceal, suppose instead that some interior type MC_0 conceals and charges P_0. We claim that for some $\Delta > 0$, any type $MC \in [MC_0 - \Delta, MC_0]$ would conceal and charge the same price P_0. The profits of a type $MC < MC_0$ when disclosing are $V_d(MC,K_d)$, where V_d is given by (A3) and K_d by (11). Note that $K_d < \epsilon/(\epsilon - 1)$ and K_d is independent of the firm's type. When type $MC < MC_0$ conceals and charges P_0, customers believe that they are facing type MC_0, so the firm's profits are

$$V_c = (P_0 - MC) \cdot Y_d^d(MC_0, P_0) = MC^{1-\epsilon} \cdot \frac{K_c - 1}{(K_c)^\epsilon} \cdot F(K_d)^{\epsilon-1},$$

where $K_c = P_0/MC$ is the markup charged by the concealing firm, and $K_d = P_0/MC_0$ is the markup charged by type MC_0, and also is the markup charged by disclosing firms. Since $MC < MC_0$, we have $K_c > K_d$. We saw previously that $K_d < \epsilon/(\epsilon - 1)$, so for Δ small enough, $MC \in [MC_0 - \Delta, MC_0]$ is close enough to MC_0, such that K_c is close enough to K_d, which implies $K_c \le \epsilon/(\epsilon - 1)$.

Now, for any $MC \in [MC_0 - \Delta, MC_0]$ with Δ small enough, we have $1 < K_d < K_c \le \epsilon/(\epsilon - 1)$. Moreover, the function $K \mapsto (K - 1)/K^\epsilon$ is strictly increasing in K for $K \in [1, \epsilon/(\epsilon - 1)]$. Hence,

$$\frac{K_c - 1}{(K_c)^\epsilon} > \frac{K_d - 1}{(K_d)^\epsilon},$$

and thus that $V_c > V_d(MC,K_d)$. We conclude that for any type $MC \in [MC_0 - \Delta, MC_0]$, it is a profitable deviation to conceal and charge P_0 so as to mimic MC_0. Here we reach a contradiction since we have previously seen that in equilibrium, concealing firms with distinct marginal costs charge distinct prices. We infer that only the lowest type can conceal in equilibrium.

Appendix B.   New Keynesian Model

Section 4 summarizes the properties of a New Keynesian model in which Calvo pricing is replaced by pricing under fairness concerns. Here, we derive these properties and present additional details. We also present the textbook New Keynesian model used as benchmark in figure 2.

Household and Firm Behavior

Household j chooses

$$\left\{ W_j(t), N_j(t), \left[Y_{ij}(t) \right]_{i=0}^1, B_j(t) \right\}_{t=0}^\infty$$

to maximize utility (17) subject to the budget constraint (18), to the labor-demand constraint $N_j(t) = N_j^d(t, W_j(t))$, and to a solvency condition. Labor demand $N_j^d(t, W_j(t))$ gives the quantity of labor that firms would hire from household j in period t at a nominal wage $W_j(t)$. The household takes as given $B_j(-1)$, and

$$\left\{ [F_i(t)]_{i=0}^1, Q(t), [P_i(t)]_{i=0}^1, V_j(t) \right\}_{t=0}^\infty.$$

To solve household j's problem, we set up the Lagrangian:

$$
\begin{aligned}
\mathcal{L}_j = \mathbb{E}_0 \sum_{t=0}^\infty \beta^t \Bigg[& \ln\left(Z_j(t) \right) - \frac{N_j(t)^{1+\eta}}{1+\eta} \\
& + \mathcal{A}_j(t) \left\{ W_j(t) N_j(t) + B_j(t-1) + V_j(t) - Q(t) B_j(t) - \int_0^1 P_i(t) Y_{ij}(t) di \right\} \\
& + \mathcal{B}_j(t) \left\{ N_j^d(t, W_j(t)) - N_j(t) \right\} \Bigg]
\end{aligned}
$$

where $\mathcal{A}_j(t)$ is the Lagrange multiplier on the budget constraint in period t and $\mathcal{B}_j(t)$ is the Lagrange multiplier on the labor-demand constraint in period t.

We first compute the first-order conditions with respect to $Y_{ij}(t)$. We know that

$$\frac{\partial Z_{ij}}{\partial Y_{ij}} = F_i$$

$$\frac{\partial Z_j}{\partial Z_{ij}} = \left(\frac{Z_{ij}}{Z_j} \right)^{-1/\epsilon} di.$$

Hence, the first-order conditions with respect to $Y_{ij}(t)$ are

(A4)
$$\left[\frac{Z_{ij}(t)}{Z_j(t)}\right]^{-1/\epsilon} \frac{F_i(t)}{Z_j(t)} = \mathcal{A}_j(t)P_i(t).$$

Manipulating and integrating the conditions (A4) over $i \in [0, 1]$, then using the definitions of Z_j and X given by (15) and (16), we obtain

(A5)
$$\mathcal{A}_j(t)X(t) = \frac{1}{Z_j(t)}.$$

Combining (A4) and (A5), we obtain the optimal consumption of good i for household j:

$$Y_{ij}(t) = \left[\frac{P_i(t)/F_i(t)}{X(t)}\right]^{-\epsilon} \frac{Z_j(t)}{F_i(t)}.$$

Integrating the consumption of good i over all households yields the output of good i:

$$Y_i(t) = Z(t)\left[\frac{P_i(t)}{X(t)}\right]^{-\epsilon} F\left(\frac{P_i(t)}{MC_i^p(t)}\right)^{\epsilon-1}.$$

Last, substituting $MC_i^p(t)$ by (14), we obtain the demand for good i:

$$Y_i^d(t, P_i(t), MC_i^p(t-1)) = Z(t)\left[\frac{P_i(t)}{X(t)}\right]^{-\epsilon} F\left(\left[\frac{\epsilon}{\epsilon-1}\right]^{1-\gamma}\left[\frac{P_i(t)}{MC_i^p(t-1)}\right]^{\gamma}\right)^{\epsilon-1}.$$

The derivatives of the function Y_i^d are

(A6)
$$-\frac{\partial \ln(Y_i^d)}{\partial \ln(P_i)} = \epsilon + (\epsilon-1)\gamma\phi(K_i^p(t)) \equiv E_i(t)$$

(A7)
$$\frac{\partial \ln(Y_i^d)}{\partial \ln(MC_i^p)} = (\epsilon-1)\gamma\phi(K_i^p(t)) = E_i(t) - \epsilon.$$

The first-order condition with respect to $B_j(t)$ is

$$Q(t)\mathcal{A}_j(t) = \beta\mathbb{E}_t\left[\mathcal{A}_j(t+1)\right].$$

Using (A5), we obtain

$$Q(t) = \beta\mathbb{E}_t\left[\frac{X(t)Z_j(t)}{X(t+1)Z_j(t+1)}\right]$$

Since the wage set by household j depends on firms' demand for its labor, we turn to firms' problems before returning to the household's problem. Firm i chooses

$$\left\{ P_i(t), Y_i(t), \left[N_{ij}(t) \right]_{j=0}^{1} \right\}_{t=0}^{\infty}$$

to maximize profits (22) subject to the production constraint (19), to the demand constraint (24), and to the law of motion of beliefs (14). The firm takes as given

$$\left\{ \left[W_j(t) \right]_{j=0}^{1}, \Gamma(t) \right\}_{t=0}^{\infty}.$$

To solve firm i's problem, we set up the Lagrangian:

$$
\begin{aligned}
\mathcal{L}_i = \mathbb{E}_0 \sum_{t=0}^{\infty} \Gamma(t) \Bigg\{ & P_i(t) Y_i(t) - \int_0^1 W_j(t) N_{ij}(t) dj \\
& + C_i(t) \left[Y_i^d(t, P_i(t), MC_i^p(t-1)) - Y_i(t) \right] + \mathcal{D}_i(t) \left[A_i(t) N_i(t)^{\alpha} - Y_i(t) \right] \\
& + \mathcal{E}_i(t) \left[(MC_i^p(t-1))^{\gamma} \left(\frac{\epsilon - 1}{\epsilon} P_i(t) \right)^{1-\gamma} - MC_i^p(t) \right] \Bigg\}
\end{aligned}
$$

where $C_i(t)$ is the Lagrange multiplier on the demand constraint in period t, $\mathcal{D}_i(t)$ is the Lagrange multiplier on the production constraint in period t, and $\mathcal{E}_i(t)$ is the Lagrange multiplier on the law of motion of the perceived marginal cost in period t.

Using the result that

$$\frac{\partial N_i}{\partial N_{ij}} = \left(\frac{N_{ij}}{N_i} \right)^{-1/\nu} dj,$$

we find that the first-order conditions with respect to $N_{ij}(t)$ for all j are

(A8)
$$W_j(t) = \alpha \mathcal{D}_i(t) A_i(t) N_i(t)^{\alpha - 1} \left[\frac{N_{ij}(t)}{N_i(t)} \right]^{-1/\nu}.$$

Manipulating and integrating the conditions (A8) over $j \in [0, 1]$, then using the definitions of N_i and W given by (20) and (21), we obtain

(A9)
$$\mathcal{D}_i(t) = \frac{W(t)}{\alpha A_i(t) N_i(t)^{\alpha - 1}}.$$

Combining (A8) and (A9), we obtain the quantity of labor that firm i hires from household j:

$$N_{ij}(t) = \left[\frac{W_j(t)}{W(t)} \right]^{-\nu} N_i(t).$$

Integrating the quantities $N_{ij}(t)$ over all firms i yields the labor demand faced by household j:

$$N_j^d(t, W_j(t)) = \left[\frac{W_j(t)}{W(t)}\right]^{-\nu} N(t).$$

Having determined the demand for labor service j, we finish solving the problem of household j. The first-order conditions with respect to $N_j(t)$ and $W_j(t)$ are

$$N_j(t)^\eta = \mathcal{A}_j(t)W_j(t) - \mathcal{B}_j(t)$$

$$\mathcal{A}_j(t)N_j(t) = -\mathcal{B}_j(t)\frac{dN_j^d}{dW_j}.$$

Since the elasticity of $N_j^d(t, W_j)$ with respect to W_j is $-\nu$, we infer from these equations that

$$\mathcal{B}_j(t) = \frac{N_j(t)^\eta}{\nu - 1}$$

$$W_j(t) = \frac{\nu}{\nu - 1} \cdot \frac{N_j(t)^\eta}{\mathcal{A}_j(t)}.$$

Using (A5), we find that household j sets its wage according to

$$\frac{W_j(t)}{X(t)} = \frac{\nu}{\nu - 1}N_j(t)^\eta Z_j(t).$$

Next, we finish solving the problem of firm i. The first-order condition with respect to $Y_i(t)$ yields $P_i(t) = C_i(t) + \mathcal{D}_i(t)$. Using (A9), we obtain

$$C_i(t) = P_i(t)\left[1 - \frac{W(t)/P_i(t)}{A_i(t)\alpha N_i(t)^{\alpha-1}}\right].$$

Firm i's nominal marginal cost is

(A10) $$MC_i(t) = \frac{W(t)}{A_i(t)\alpha N_i(t)^{\alpha-1}}.$$

Hence, the first-order condition implies

$$C_i(t) = P_i(t)\left[1 - \frac{MC_i(t)}{P_i(t)}\right].$$

With the quasi elasticity $D_i(t) = K_i(t)/(K_i(t) - 1)$, we rewrite the first-order condition as

(A11)
$$C_i(t) = \frac{P_i(t)}{D_i(t)}.$$

The first-order condition with respect to $P_i(t)$ is

$$0 = Y_i(t) + C_i(t)\frac{\partial Y_i^d}{\partial P_i} + (1 - \gamma)\mathcal{E}_i(t)\frac{MC_i^p(t)}{P_i(t)},$$

which implies

$$0 = 1 - \frac{C_i(t)}{P_i(t)}E_i(t) + (1 - \gamma)\frac{\mathcal{E}_i(t)}{Y_i(t)K_i^p(t)}.$$

Combining this equation with (A11) yields

(A12)
$$\frac{E_i(t)}{D_i(t)} - 1 = (1 - \gamma)\frac{\mathcal{E}_i(t)}{Y_i(t)K_i^p(t)}.$$

Finally, the first-order condition with respect to $MC_i^p(t)$ is

$$0 = \mathbb{E}_t\left[\frac{\Gamma(t + 1)}{\Gamma(t)}C_i(t + 1)\frac{\partial Y_i^d}{\partial MC_i^p}\right] + \gamma\mathbb{E}_t\left[\frac{\Gamma(t + 1)}{\Gamma(t)}\mathcal{E}_i(t + 1)\frac{MC_i^p(t + 1)}{MC_i^p(t)}\right] - \mathcal{E}_i(t).$$

Multiplying this equation by $MC_i^p(t)/P_i(t)$, and using (A7), we get

$$0 = \mathbb{E}_t\left[\frac{\Gamma(t + 1)}{\Gamma(t)P_i(t)}C_i(t + 1)Y_i(t + 1)(E_i(t + 1) - \epsilon) + \gamma\frac{\Gamma(t + 1)}{\Gamma(t)P_i(t)}\mathcal{E}_i(t + 1)MC_i^p(t + 1)\right] - \mathcal{E}_i(t)\frac{MC_i^p(t)}{P_i(t)}.$$

We now focus on a symmetric equilibrium, where $P_i(t) = P(t)$, $Z(t) = F(t)Y(t)$, and $X(t) = P(t)/F(t)$. Using $\Gamma(t) = \beta^t[X(0)Z(0)]/[X(t)Z(t)]$, we find that in such equilibrium,

$$\frac{\Gamma(t + 1)}{\Gamma(t)P_i(t)} = \beta\frac{X(t)}{X(t + 1)P(t)} \cdot \frac{Z(t)}{Z(t + 1)} = \frac{\beta}{P(t + 1)} \cdot \frac{Y(t)}{Y(t + 1)}.$$

Hence, the equation becomes

$$0 = \beta\mathbb{E}_t\left[C(t + 1)\frac{Y(t)}{P(t + 1)}(E(t + 1) - \epsilon) + \gamma\mathcal{E}(t + 1)\frac{Y(t)}{Y(t + 1)} \cdot \frac{MC^p(t + 1)}{P(t + 1)}\right] - \mathcal{E}(t)\frac{MC^p(t)}{P(t)}.$$

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Using (A11) and $K^p(t) = P(t)/MC^p(t)$, and dividing by $Y(t)$, we now obtain

$$0 = \beta \mathbb{E}_t \left[\frac{E(t+1) - \epsilon}{D(t+1)} + \gamma \frac{\mathcal{E}(t+1)}{Y(t+1)K^p(t+1)} \right] - \frac{\mathcal{E}(t)}{Y(t)K^p(t)}.$$

Finally, multiplying by $1 - \gamma$ and using (A12), we get

$$0 = \beta \mathbb{E}_t \left[(1 - \gamma) \frac{E(t+1) - \epsilon}{D(t+1)} + \gamma \frac{E(t+1)}{D(t+1)} - \gamma \right] - \frac{E(t)}{D(t)} + 1.$$

Rearranging the terms, we finally obtain

$$\beta \mathbb{E}_t \left[\frac{E(t+1) - (1 - \gamma)\epsilon}{D(t+1)} \right] = \frac{E(t)}{D(t)} - (1 - \gamma\beta).$$

This equation gives the quasi elasticity $D(t)$ and thus the goods-market markup $K(t)$.

Equilibrium Dynamics

We derive the dynamical system describing a symmetric equilibrium.

We first rework the law of motion for the perceived marginal cost $MC^p(t)$, given by (14), to obtain a law of motion for the perceived markup, $K^p(t) = P(t)/MC^p(t)$:

$$K^p(t) = \left(\frac{\epsilon}{\epsilon - 1} \right)^{1-\gamma} [K^p(t-1)]^\gamma \left[\frac{P(t)}{P(t-1)} \right]^\gamma.$$

Taking the log of this equation, and using $\pi(t) = p(t) - p(t-1)$, we find

(A13) $$k^p(t) = (1 - \gamma) \ln \left(\frac{\epsilon}{\epsilon - 1} \right) + \gamma [\pi(t) + k^p(t-1)].$$

Subtracting the steady-state values of both sides yields

(A14) $$\widehat{k^p}(t) = \gamma \left[\widehat{\pi}(t) + \widehat{k^p}(t-1) \right].$$

Second, we take the log of the Euler equation (27):

$$y(t) = \mathbb{E}_t[y(t+1)] + \mathbb{E}_t[\pi(t+1)] + \rho - i(t),$$

where $\rho = -\ln(\beta)$ is the time discount rate. Combining this equation with the monetary-policy rule (23) yields

$$y(t) + \mu\pi(t) = \mathbb{E}_t[y(t+1)] + \mathbb{E}_t[\pi(t+1)] + \rho - i_0(t).$$

Subtracting the steady-state values of both sides, we obtain

(A15)
$$\widehat{y}(t) + \mu\widehat{\pi}(t) = \mathbb{E}_t[\widehat{y}(t+1)] + \mathbb{E}_t[\widehat{\pi}(t+1)] - \widehat{i_0}(t).$$

Then, the log-linear version of the production function (19) is

(A16)
$$\widehat{y}(t) = \widehat{a}(t) + \alpha\widehat{n}(t).$$

Combining (A15) with (A16) yields the IS equation:

(A17)
$$\alpha\widehat{n}(t) + \mu\widehat{\pi}(t) = \alpha\mathbb{E}_t[\widehat{n}(t+1)] + \mathbb{E}_t[\widehat{\pi}(t+1)] - \widehat{i_0}(t) - \widehat{a}(t) + \mathbb{E}_t[\widehat{a}(t+1)].$$

Next, we compute a log-linear approximation of the price elasticity (28):

(A18)
$$\widehat{e}(t) = \Omega_0 \ \widehat{k^p}(t),$$

where
$$\Omega_0 = \frac{\overline{E} - \epsilon}{\overline{E}}\,\overline{\chi} = \frac{(\epsilon-1)\,\gamma\,\overline{\phi}\,\overline{\chi}}{\epsilon + (\epsilon-1)\,\gamma\,\overline{\phi}}.$$

(We have used $\chi = d\ln(\phi)/d\ln(K^p)$.) We also compute a log-linear approximation of the quasi elasticity $D = K/(K-1)$:
$$\widehat{d}(t) = -\Omega_1 \ \widehat{k}(t),$$

where
$$\Omega_1 = \frac{\overline{K}}{\overline{K}-1} - 1 = \frac{1}{\overline{K}-1} = (\epsilon-1)\left[1 + \frac{(1-\beta)\gamma}{1-\beta\gamma}\,\overline{\phi}\right].$$

(We have used (39) to get the value of $\overline{K}$.) The log-linear version of (31) is $\widehat{k}(t) = -(1+\eta)\,\widehat{n}(t)$. Hence, we obtain

(A19)
$$\widehat{d}(t) = (1+\eta)\,\Omega_1\,\widehat{n}(t).$$

The next step is to compute a log-linear approximation of the pricing equation (30):

(A20)
$$\widehat{e}(t) - \widehat{d}(t) = \Omega_3\,\mathbb{E}_t[\widehat{e}(t+1)] - \Omega_2\,\mathbb{E}_t\left[\widehat{d}(t+1)\right],$$

where

$$\Omega_3 = \left[\frac{\overline{E} - (1 - \gamma\beta)\overline{D}}{\overline{E}}\right]\left[\frac{\overline{E}}{\overline{E} - (1 - \gamma)\epsilon}\right] = \beta$$

$$\Omega_2 = \frac{\overline{E} - (1 - \gamma\beta)\overline{D}}{\overline{E}} = \beta\gamma\,\frac{\epsilon + (\epsilon - 1)\,\overline{\phi}}{\epsilon + (\epsilon - 1)\,\gamma\,\overline{\phi}}.$$

To simplify Ω_3 and Ω_2, we have used (28) and (39), which imply the following results:

$$\overline{D} = 1 + (\epsilon - 1)\left[1 + \frac{(1 - \beta)\gamma}{1 - \beta\gamma}\overline{\phi}\right]$$

$$(1 - \gamma\beta)\overline{D} = (1 - \gamma\beta) + (\epsilon - 1)\left[(1 - \gamma\beta) + (1 - \beta)\gamma\overline{\phi}\right]$$

$$= (1 - \gamma\beta)\,\epsilon + (\epsilon - 1)(1 - \beta)\gamma\overline{\phi}$$

$$\overline{E} - (1 - \gamma\beta)\,\overline{D} = \beta\gamma\left[\epsilon + (\epsilon - 1)\,\overline{\phi}\right]$$

$$\overline{E} - (1 - \gamma)\,\epsilon = \gamma\left[\epsilon + (\epsilon - 1)\,\overline{\phi}\right].$$

Finally, combining (A18), (A19), and (A20), we obtain

(A21) $\qquad \Omega_0\,\widehat{k^p}(t) - (1 + \eta)\,\Omega_1\,\widehat{n}(t) = \beta\,\Omega_0\,\mathbb{E}_t\left[\widehat{k^p}(t + 1)\right] - (1 + \eta)\,\Omega_1\,\Omega_2\,\mathbb{E}_t[\widehat{n}(t + 1)].$

We define

$$\lambda_1 = (1 + \eta)\frac{\Omega_1}{\Omega_0} = (1 + \eta)\frac{\epsilon + (\epsilon - 1)\,\gamma\,\overline{\phi}}{\gamma\,\overline{\phi}\,\overline{\chi}}\left[1 + \frac{(1 - \beta)\gamma}{1 - \beta\gamma}\,\overline{\phi}\right]$$

$$\lambda_2 = (1 + \eta)\frac{\Omega_1\,\Omega_2}{\Omega_0} = (1 + \eta)\,\beta\,\frac{\epsilon + (\epsilon - 1)\overline{\phi}}{\overline{\phi}\,\overline{\chi}}\left[1 + \frac{(1 - \beta)\gamma}{1 - \beta\gamma}\,\overline{\phi}\right].$$

Dividing (A21) by Ω_0, and using the definitions of λ_1 and λ_2, we obtain the Phillips curve:

(A22) $\qquad \lambda_1\,\widehat{n}(t) = (1 - \beta\gamma)\,\widehat{k^p}(t) - \beta\,\gamma\,\mathbb{E}_t[\widehat{\pi}(t + 1)] + \lambda_2\,\mathbb{E}_t[\widehat{n}(t + 1)].$

To conclude, we combine (A14), (A17), and (A22) to obtain the dynamical system describing the equilibrium:

$$\begin{bmatrix} \gamma & \gamma & 0 \\ 0 & \mu & \alpha \\ 0 & 0 & \lambda_1 \end{bmatrix}\begin{bmatrix} \widehat{k^p}(t - 1) \\ \widehat{\pi}(t) \\ \widehat{n}(t) \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & \alpha \\ 1 - \beta\gamma & -\beta\gamma & \lambda_2 \end{bmatrix}\begin{bmatrix} \widehat{k^p}(t) \\ \mathbb{E}_t[\widehat{\pi}(t + 1)] \\ \mathbb{E}_t[\widehat{n}(t + 1)] \end{bmatrix} - \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}\epsilon(t),$$

where

$$\epsilon(t) = \widehat{i_0}(t) + \widehat{a}(t) + \mathbb{E}_t[\widehat{a}(t+1)]$$

is an exogenous shock realized at time t. The inverse of the matrix on the right-hand side is

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & \alpha \\ 1 - \beta\gamma & -\beta\gamma & \lambda_2 \end{bmatrix}^{-1} = \begin{bmatrix} 1 & 0 & 0 \\ \frac{(1-\beta\gamma)\alpha}{\lambda_2+\alpha\beta\gamma} & \frac{\lambda_2}{\lambda_2+\alpha\beta\gamma} & \frac{-\alpha}{\lambda_2+\alpha\beta\gamma} \\ \frac{\beta\gamma-1}{\lambda_2+\alpha\beta\gamma} & \frac{\beta\gamma}{\lambda_2+\alpha\beta\gamma} & \frac{1}{\lambda_2+\alpha\beta\gamma} \end{bmatrix}.$$

Premultiplying the dynamical system by the inverse matrix, we rewrite the system as follows:

$$\begin{bmatrix} \widehat{k^p}(t) \\ \mathbb{E}_t[\widehat{\pi}(t+1)] \\ \mathbb{E}_t[\widehat{n}(t+1)] \end{bmatrix} = \mathbf{A} \begin{bmatrix} \widehat{k^p}(t-1) \\ \widehat{\pi}(t) \\ \widehat{n}(t) \end{bmatrix} + \mathbf{B} \cdot \epsilon(t)$$

where

$$\mathbf{A} = \begin{bmatrix} \gamma & \gamma & 0 \\ \frac{(1-\beta\gamma)\alpha\gamma}{\lambda_2+\alpha\beta\gamma} & \frac{\lambda_2\mu+\alpha\gamma(1-\beta\gamma)}{\lambda_2+\alpha\beta\gamma} & \frac{(\lambda_2-\lambda_1)\alpha}{\lambda_2+\alpha\beta\gamma} \\ \frac{-(1-\beta\gamma)\gamma}{\lambda_2+\alpha\beta\gamma} & \frac{[\beta\mu+\beta\gamma-1]\gamma}{\lambda_2+\alpha\beta\gamma} & \frac{\lambda_1+\alpha\beta\gamma}{\lambda_2+\alpha\beta\gamma} \end{bmatrix} \quad \text{and} \quad \mathbf{B} = \begin{bmatrix} 0 \\ \frac{\lambda_2}{\lambda_2+\alpha\beta\gamma} \\ \frac{\beta\gamma}{\lambda_2+\alpha\beta\gamma} \end{bmatrix}.$$

This dynamical system determines employment $\widehat{n}(t)$, inflation $\widehat{\pi}(t)$, and perceived markup $\widehat{k^p}(t)$.

Using (19), (23), and (31), we obtain the other variables from these three variables: output is given by $\widehat{y}(t) = \widehat{a}(t) + \alpha\widehat{n}(t)$; the nominal and real interest rates by $\widehat{i}(t) = \widehat{i_0}(t) + \mu\widehat{\pi}(t)$ and $\widehat{r}(t) = \widehat{i_0}(t) + (\mu - 1)\widehat{\pi}(t)$; and the goods-market markup by $\widehat{k}(t) = -(1 + \eta)\widehat{n}(t)$.

Calibration

Using the derivations above, we study the behavior of a single firm i that faces an exogenous demand curve and a stochastic marginal cost. This is a simplified version of the firm problem in the New Keynesian model, abstracting from hiring decisions. The objective is to calibrate three key parameters of the New Keynesian model—ϵ, ξ, and γ—by matching the dynamics of the marginal-cost passthrough obtained in simulation to those estimated in the data.

Firm i chooses $\{P_i(t), Y_i(t)\}_{t=0}^{\infty}$ to maximize

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[P_i(t) - MC_i(t) \right] Y_i(t),$$

subject to the demand constraint

$$\text{(A23)} \qquad Y_i^d(P_i(t), MC_i^p(t-1)) = Z\, P_i(t)^{-\epsilon} F\left(\left[\frac{\epsilon}{\epsilon-1}\right]^{1-\gamma}\left[\frac{P_i(t)}{MC_i^p(t-1)}\right]^{\gamma}\right)^{\epsilon-1}.$$

and to the law of motion of beliefs (14). The level of aggregate demand, Z, is exogenous and constant. The nominal marginal cost, $MC_i(t)$, is exogenous and stochastic. Since we assume that there is no underlying inflation, $MC_i(t)$ is constant in steady state.

To solve the firm's problem, we set up the Lagrangian:

$$\mathcal{L}_i = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Bigg[(P_i(t) - MC_i(t))\, Y_i(t)$$

$$+ C_i(t)\left\{ Y_i^d(P_i(t), MC_i^p(t-1)) - Y_i(t) \right\}$$

$$+ \mathcal{E}_i(t)\left\{ [MC_i^p(t-1)]^{\gamma}\left(\frac{\epsilon-1}{\epsilon}P_i(t)\right)^{1-\gamma} - MC_i^p(t) \right\} \Bigg]$$

where $C_i(t)$ is the Lagrange multiplier on the demand constraint in period t, and $\mathcal{E}_i(t)$ is the Lagrange multiplier on the law of motion of the perceived marginal cost in period t.

The first-order condition with respect to $Y_i(t)$ yields

$$C_i(t) = P_i(t)\left[1 - \frac{MC_i(t)}{P_i(t)}\right].$$

Using the markup $K_i(t) = P_i(t)/MC_i(t)$ and the quasi elasticity $D_i(t) = K_i(t)/(K_i(t)-1)$, we rewrite the first-order condition as

$$\text{(A24)} \qquad C_i(t) = \frac{P_i(t)}{D_i(t)}.$$

The first-order condition with respect to $P_i(t)$ is

$$0 = Y_i(t) + C_i(t)\frac{\partial Y_i^d}{\partial P_i} + (1-\gamma)\,\mathcal{E}_i(t)\frac{MC_i^p(t)}{P_i(t)}.$$

Using (A6), we infer

$$0 = 1 - \frac{C_i(t)}{P_i(t)}\cdot E_i(t) + (1-\gamma)\cdot\frac{\mathcal{E}_i(t)}{Y_i(t)}\cdot\frac{MC_i^p(t)}{P_i(t)}.$$

Combining this equation with (A24) yields

$$(A25) \qquad \frac{E_i(t)}{D_i(t)} - 1 = (1 - \gamma) \cdot \frac{\mathcal{E}_i(t)}{Y_i(t)} \cdot \frac{MC_i^p(t)}{P_i(t)}.$$

Last, the first-order condition with respect to $MC_i^p(t)$ is

$$0 = \beta \, \mathbb{E}_t \left[C_i(t + 1) \frac{\partial Y_i^d}{\partial MC_i^p} + \gamma \, \mathcal{E}_i(t + 1) \frac{MC_i^p(t + 1)}{MC_i^p(t)} \right] - \mathcal{E}_i(t).$$

Multiplying this equation by $(1 - \gamma)MC_i^p(t)$, and using (A7), we get

$$(1 - \gamma)\mathcal{E}_i(t)MC_i^p(t) = \beta \mathbb{E}_t \left[(1 - \gamma)C_i(t + 1)Y_i(t + 1)\left(E_i(t + 1) - \epsilon\right) + \gamma(1 - \gamma)\mathcal{E}_i(t + 1)MC_i^p(t + 1) \right].$$

Hence, using (A24) and (A25), the equation becomes

$$\frac{Y_i(t)P_i(t)}{D_i(t)} \left[E_i(t) - D_i(t) \right] = \beta \mathbb{E}_t \left[\frac{Y_i(t + 1)P_i(t + 1)}{D_i(t + 1)} \left\{ (1 - \gamma)\left(E_i(t) - \epsilon\right) + \gamma\left(E_i(t + 1) - D_i(t + 1)\right) \right\} \right].$$

We denote the profits of firm i in period t by $V_i(t) = \left[P_i(t) - MC_i(t) \right] Y_i(t)$. We have

$$(A26) \qquad V_i(t) = Y_i(t)P_i(t) \left[1 - \frac{MC_i(t)}{P_i(t)} \right] = Y_i(t)P_i(t) \left[1 - \frac{1}{K_i(t)} \right] = \frac{Y_i(t)P_i(t)}{D_i(t)}.$$

Thus, the first-order condition simplifies to

$$(A27) \qquad V_i(t) \left[E_i(t) - D_i(t) \right] = \beta \mathbb{E}_t [V_i(t + 1) \left[E_i(t) - (1 - \gamma)\epsilon - \gamma D_i(t + 1) \right]].$$

The eight equilibrium variables $P_i(t)$, $MC_i^p(t)$, $Y_i(t)$, $V_i(t)$, $K_i(t)$, $K_i^p(t)$, $E_i(t)$, and $D_i(t)$. The eight equilibrium conditions describing firm i's pricing are (14), (A23), (A26), (A27), $D_i(t) = K_i(t)/(K_i(t) - 1)$, $E_i(t) = \epsilon + (\epsilon - 1)\gamma\phi(K_i^p(t))$, $K_i^p(t) = P_i(t)/MC_i^p(t)$, and $K_i(t) = P_i(t)/MC_i(t)$.

To simulate the dynamics of the marginal-cost passthrough, we solve this nonlinear dynamical system of eight equations (using Dynare). We assume that the firm is in steady state for some marginal cost $\overline{MC_i}$ and impose at time 0 an unexpected and permanent one-percent increase in MC_i. (The steady-state values of the variables are the same as in the New Keynesian model.) We compute the response of the variables to this shock. Passthrough dynamics are then obtained by computing the percentage change of firm i's price over time:

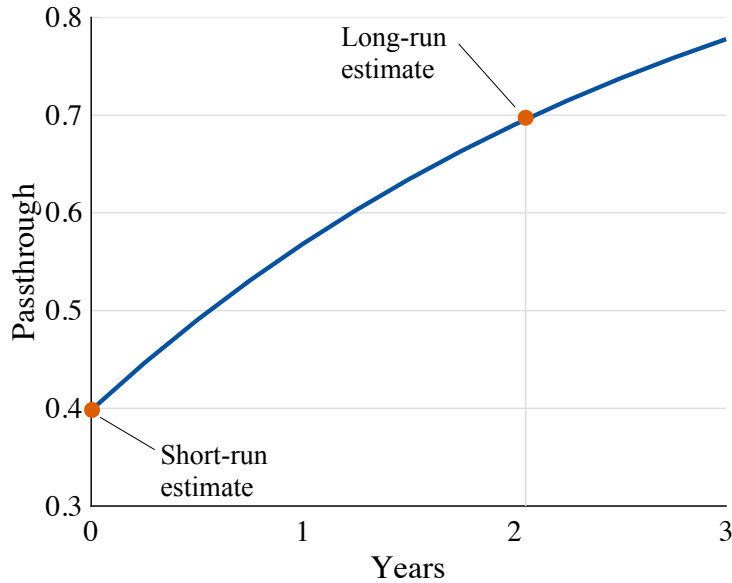$$\sigma_i(t) = \frac{P_i(t) - \overline{P_i}}{\overline{P_i}} \times 100.$$

Figure A1. Simulated Passthrough Dynamics and Estimated Passthroughs

Notes: The simulated passthrough dynamics are obtained from the pricing model in appendix B, under the calibration in table 4. The passthrough estimates are discussed in section 4.4.

We then match simulated passthrough dynamics to estimated passthrough dynamics in order to calibrate three parameters of the New Keynesian model: the elasticity of substitution between goods, ϵ, the concern for fairness, ξ, and the degree of underinference, γ. We aim to calibrate the model such that the marginal-cost passthrough is 0.4 on impact and 0.7 after two years. Since we are calibrating three parameters, we need a third empirical moment: we target a steady-state markup of 1.5.

To calibrate the parameters, we initialize ξ and γ to some values. Then we compute ϵ using these values, (39), and $\overline{K} = 1.5$. Since we focus on a zero-inflation steady state, (38) implies that $\overline{K^p} = e/(\epsilon - 1)$ and $\overline{F} = 1$, so in (39), $\phi(\overline{K^p}) = \xi\epsilon/(\epsilon - 1)$. Then, using the values of ξ, γ, and ϵ, we simulate passthrough dynamics. We repeat the simulation for different values of ξ and γ until we obtain a passthrough of 0.4 on impact and 0.7 after 2 years. We match these targets with $\xi = 9$ and $\gamma = 0.8$; the corresponding value of ϵ is 2.2. The simulated passthrough dynamics under this calibration are displayed in figure A1.

Textbook Model

We describe the textbook model used as benchmark in the simulations. The model is borrowed from Gali (2008, chap. 3).

The equilibrium dynamics around the zero-inflation steady state are determined by two difference equations: the IS equation and the Phillips curve. The IS equation is given by (32), as in the model with fairness. This IS equation is equivalent to equation (12) in Gali (2008, chap. 3), but it also incorporates the production function (19) and monetary-policy rule (23), and it is simplified by assuming log consumption utility.

The Phillips curve is given by

$$\widehat{\pi}(t) = \beta \mathbb{E}_t[\widehat{\pi}(t+1)] + \kappa \alpha \widehat{n}(t)$$

where

$$\kappa \equiv \frac{1+\eta}{\alpha} \cdot \frac{(1-\theta)(1-\beta\theta)}{\theta} \cdot \frac{\alpha}{\alpha + (1-\alpha)\,\epsilon},$$

and θ is the fraction of firms keeping their prices unchanged each period. The Phillips curve is not the same as in the model with fairness because pricing is different. The Phillips curve is obtained from equation (16) in Gali (2008, chap. 3), using log consumption utility. One of the implications of log utility is that the output gap in the equation (16) is equal to $\alpha \widehat{n}(t)$.[17]

The IS equation and Phillips curve jointly determine employment $\widehat{n}(t)$ and inflation $\widehat{\pi}(t)$. The other variables directly follow from these two variables. The real interest rate is given by the monetary-policy rule (23): $\widehat{r}(t) = \widehat{i_0}(t) + (\mu-1)\,\widehat{\pi}(t)$. The goods-market markup is given by (31): $\widehat{k}(t) = -(1+\eta)\,\widehat{n}(t)$. Since households observe both prices and costs in the textbook model, perceived and actual goods-market markups are equal: $\widehat{k^p}(t) = \widehat{k}(t)$. Last, output is given by the production function (19): $\widehat{y}(t) = \widehat{a}(t) + \alpha \widehat{n}(t)$.

References

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[17]The output gap is the gap between the actual and natural levels of output. The natural level of output is reached when prices are flexible, so when the goods-market markup is $\epsilon/(\epsilon-1)$. Moreover, when the markup is $\epsilon/(\epsilon-1)$, the markup is at its steady-state level, so employment is at its steady-state level (equation (31)). Hence, using (19), we infer that the log of output is $y(t) = a(t) + \alpha n(t)$ while the log of natural output is $y^n(t) = a(t) + \alpha \bar{n}$. To conclude, the output gap is $y(t) - y^n(t) = \alpha \widehat{n}(t)$.