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Do menu costs lead to hysteresis in aggregate output? The experiences of some agent-based simulations

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ABSTRACT

The transitory shock of the financial crisis of 2008 pushed most economies to permanently lower-level growth paths than those prevalent before the crisis, which can be considered as a manifestation of hysteresis. It is well known that some fixed adjustment costs lead to hysteresis in aggregate output. This paper investigates within an agent-based model, whether the fixed costs of price adjustment (menu costs) lead to the same result. Hysteresis emerges in some simple variants of the model independently of firms being assumed boundedly or perfectly rational, but these model variants fit to the empirical data poorly. The model's empirical performance can be improved by assuming that firms are hit by idiosyncratic productivity shocks, but these shocks eliminate hysteresis generated by menu costs. However, hysteresis survives even in their presence, if it is generated by demand-supply interactions, i.e., positive feedbacks from the output gap to potential output. Our conclusion is that if one would like menu costs to serve as an at least as relevant explanation for the hysteretic dynamics of aggregate output as demand-supply interactions, one has to find an alternative assumption to replace idiosyncratic productivity shocks as a mechanism to assure good empirical fit for the model.

KEYWORDS

hysteresis, menu costs, agent-based model, demand-supply interactions, long-run monetary non-neutrality

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1. INTRODUCTION

During the slow recovery from the global financial crisis of 2008, an interesting macroeconomic puzzle has emerged: after the transitory shock of the crisis died away, most developed economies did not return to their pre-crisis growth paths, but they settled down on growth paths characterized by permanently lower levels and in many cases, by permanently lower growth rates, as well. Many economists interpret this phenomenon as a manifestation of *hysteresis* (Halmai – Vásáry 2011; Ball 2014; Hall 2014; Blanchard et al. 2015; Török – Konka 2018). Hysteresis can be observed in a dynamic system, if a transitory shock exerts a permanent effect on its steady state (Amable et al. 1993; Göcke 2002). The potential presence of hysteresis in the empirical dynamics of GDP is puzzling, since it contradicts the core concept of the New Neoclassical Synthesis (NNS), which dominates mainstream macroeconomics. According to the NNS, the long-run growth path of an economy is independent of its short-run cyclical fluctuations. The long-run – or potential – growth path is exogenously determined by supply-side factors, such as the growth rate of productivity. Demand-side factors affect real variables in the short run because of some imperfections of market adjustment, but in the long run, the price mechanism coordinates aggregate demand growth with the exogenously given growth rate of aggregate supply perfectly (Woodford 2003; Galí 2008). However, if hysteresis can actually be observed in the post-crisis dynamics of empirical GDP, then transitory demand shocks, such as the financial crisis of 2008 must have an effect on the long-run growth paths of economies, meaning that demand-side factors affect real variables not only in the short run, but in the long run, as well.

The above-mentioned empirical observations have led to a revival of interest for the theories of hysteresis among macroeconomists. It has been the subject of research for a long time what the most important economic mechanisms responsible for hysteretic macrodynamics are. According to the most popular explanations,

- the loss of skills by the long-term unemployed during recessions (Phelps 1972; Cross 1987),
- an insider-outsider mechanism of wage bargaining (Blanchard – Summers 1986),
- a positive feedback from short-run economic growth to the growth rate of productivity, known as the Kaldor-Verdoorn law (Verdoorn 1949; Kaldor 1957), or
- some fixed costs of market adjustment

result in hysteresis. These fixed costs are usually associated with the market entry of firms (Baldwin – Krugman 1989; Dixit 1992), with the initiation of their investment activities (Bassi – Lang 2016), or with other types of economic activities that involve switching the state of an economic agent (Cross 1994).

New Keynesian macroeconomists often associate fixed adjustment costs with price changes, which they label as *menu costs*[1] (Barro 1972; Mankiw 1985; Blanchard – Kiyotaki 1987). Still, only two papers can be found in the literature, which mention the possibility that hysteresis may emerge in the presence of menu costs (Delgado 1991; Dixit 1991). In recent dynamic stochastic general equilibrium (DSGE) type of menu cost models (Golosov – Lucas 2007; Nakamura –

[1] Menu costs are the costs of repricing goods. Their name stems from the fact that a restaurant has to reprint the menu in case of changing prices, but menu costs are far more general. They involve the costs of drawing up new guidelines for salespeople, informing customers about the new price, remarking prices on shelves and shelf labels, and most importantly, the time and effort required to decide about the new price (Levy et al. 1997; Dutta et al. 1999; Zbaracki et al. 2004; Mishkin 2015).

Steinsson 2010; Midrigan 2011; Alvarez et al. 2016; Karádi – Reiff 2019), there is no sign of hysteresis. The central research question of this paper is motivated by this puzzle: do menu costs lead to hysteresis in the dynamics of real aggregate output? If yes, under what kinds of conditions? If there exists a theoretical model, in which the presence of menu costs causes hysteresis, a further question naturally arises: is this model empirically relevant compared to those that do not produce hysteretic dynamics?

If menu costs turned out to be able to lead to hysteresis in aggregate output under empirically plausible conditions, this finding would have important practical implications for the conduct of monetary policy. If *transitory* shocks to the *growth rate* of nominal aggregate demand – which are equivalent to *permanent* shocks to its *level* – lead to permanent changes in real output, then the *long-run neutrality of money* fails (Lucas 1996; Bullard 1999). According to the NNS, money is not neutral in the *short run*, since prices do not adjust to monetary shocks immediately because of the presence of nominal rigidities (Woodford 2003; Galí 2008). But in the long run, price adjustment is perfect, thus long-run monetary neutrality prevails. If money is actually neutral in the long run, then central banks are not able to exert long-run effects on real economic activity, hence they should primarily focus on maintaining a low and stable inflation rate. Thus, the lack of hysteresis in the dynamics of real output is a core preassumption behind the optimality of the policy of strict inflation targeting suggested to monetary authorities by early New Keynesian monetary theories (Woodford 2003; Galí 2008).

However, if money is not neutral in the long run, then central banks should put more emphasis on following real economic targets besides their primary target of maintaining a low and stable rate of inflation. According to Fontana and Palacio-Vera (2007), they should follow a monetary strategy labeled as the *flexible opportunistic approach* of inflation targeting, which means that they should not react to small inflationary shocks by restrictive monetary policy measures, thereby they can avoid causing long-run damages to the real economy. Instead, they should wait for a deflationary shock to take the inflation rate back to the vicinity of its target value. Of course, a monetary restriction is unavoidable in case of a large inflationary shock. In case of deflationary shocks, central banks should not wait for anything, as a monetary expansion may lead to long-run real benefits.

It has to be noted that New Keynesian macroeconomists have also started to come up with models for analyzing hysteresis and long-run monetary non-neutrality in recent years (Anzoategui et al. 2019; Garga – Singh 2021; Galí 2022), as well as with empirical evidence for the long-run real effects of monetary shocks (Jorda et al. 2020). Their usual conclusion regarding monetary policy is that central banks should follow additional real economic targets besides the usually targeted inflation rate and the output gap. The level of the unemployment rate (Galí 2022) or the cumulative deviation of the growth rate of total factor productivity from its steady state value (Garga – Singh 2021) may serve as appropriate additional targets depending on the exact nature of hysteresis. Of course, all these monetary policy implications are dependent on the applied model frameworks, which all assume in line with the NNS that inflation is mainly driven by excess demand in the goods market.[2]

[2]Rochon – Setterfield (2007) base their model on another assumption, which is more in line with the perspective of post-Keynesian macroeconomics, and according to which inflation is the result of conflicting nominal income claims of workers and capitalists. They show that under this assumption, fiscal policy and income policy might also be efficient in terms of stabilizing inflation and output, even if long-run monetary neutrality fails. This gives the opportunity for central banks to set a fixed or a quasi-fixed interest rate based on fairness considerations.

Post-Keynesian macroeconomists have argued against long-run monetary neutrality for a much longer time than some New Keynesians on theoretical grounds (Davidson 1987; Cottrell 1994; Palacio-Vera 2005; Fontana – Palacio-Vera 2007; Kriesler – Lavoie 2007), as well as by coming up with convincing empirical evidence for the long-run real effects of monetary shocks (Atesoglu 2001; Atesoglu – Emerson 2009; Stockhammer – Sturn 2011). One of the economic mechanisms, with the help of which they argue against long-run monetary neutrality is the presence of *nonlinear price adjustment* in the economy. It means that within an intermediate range of real economic activity, prices do not react to exogenous shocks, therefore the short-run, as well as the long-run Phillips curve is horizontal (Palacio-Vera 2005; Kriesler – Lavoie 2007). The typical post-Keynesian explanation for this nonlinear nature of price adjustment is that decreasing returns do not prevail in the vicinity of potential real activity, hence positive demand shocks lead to price increases only if they are large enough for decreasing returns to show up in production. It is worth noting that the presence of menu costs leads to a similar nonlinear price decision rule, because firms will not find it reasonable to adjust their prices to a small demand shock, if the fixed adjustment cost is not compensated by the anticipated benefits of changing the price. Thus, nonlinear price adjustment as an explanation for the failure of long-run monetary neutrality can be grounded with a post-Keynesian, as well as with a New Keynesian foundation. The consequences of its post-Keynesian interpretation regarding long-run monetary non-neutrality suggest that its New Keynesian interpretation, the presence of menu costs may actually lead to hysteresis in real aggregate output.

It will be assumed in the paper that the *transitory* shocks, which may lead to hysteretic effects in the real economy, hit the *growth rate* of nominal aggregate demand. This way, the results will be easy to interpret from the point of view of long-run monetary non-neutrality, which requires a *permanent* shock to the *level* of nominal aggregate demand to have long-run real effects. The assumption facilitates comparison with DSGE-type menu cost models, as well, in which transitory monetary shocks are also assumed to hit the growth rate of nominal aggregate demand. One may argue that the permanent effects on the level of real economic activity should be the results of transitory shocks to the *level* of nominal aggregate demand in order to be appropriately called hysteresis. If they are caused by transitory shocks to the *growth rate* of nominal aggregate demand, they may be more appropriately labeled as *demand-led growth*. Hysteresis is a general property of a dynamic system, according to which transitory shocks have permanent effects on its steady state, while demand-led growth refers to any case, when the long-run evolution of potential real activity is – at least in part – shaped by demand-side factors (Setterfield 2002).[3] There are two reasons why the label *hysteresis* is used in this paper instead of the label *demand-led growth*. First, the possible permanent real effects of the financial crisis of 2008, which constitute the core empirical motivation behind the theoretical research questions of the paper, are usually referred to as hysteresis in the recent literature. Second, the results of the paper would remain qualitatively unchanged, if transitory shocks were assumed to hit the level of nominal aggregate demand instead of its growth rate.[4]

[3]See Fontana – Palacio-Vera (2007) for a more detailed description about the roles of demand-led growth and hysteresis in generating long-run monetary non-neutrality.

[4]Some results are available from the author upon request.

To find answers for the research questions, an agent-based menu cost model is developed, which allows studying the behaviour and the interactions of many heterogeneous agents rather than assuming the existence of a representative one (Leijonhufvud 2006; Tesfatsion 2006). Agent-based models are becoming increasingly popular tools in macroeconomic research (Dosi et al. 2010; Delli Gatti et al. 2011; Dawid et al. 2012; Gaffeo et al. 2015; Fagiolo – Roventini 2017; Guerini et al. 2018). Babutsidze (2012) presents an example for an agent-based menu cost model. Setterfield and Gouri Suresh (2016) argue that agent-based models are especially useful for studying hysteresis, and more generally, path-dependent macrodynamics, since the most complex, strong variant of hysteresis (Amable et al. 1993, 1994; Cross 1994; Göcke 2002; Setterfield 2009), as well as many other path-dependent phenomena are *emergent*: they cannot be observed at the micro level of the economy, but they *emerge* at the macro level as a result of interactions between heterogeneous microeconomic agents. Agent-based models have been developed for the analysis of such emergent phenomena (Tesfatsion 2006).[5]

The focus of this paper is not on the quantitative aspects of hysteresis that might emerge in the presence of menu costs, its scope is limited to analyzing qualitatively if the dynamics of aggregate output is hysteretic, or not. However, it is aimed to be assessed, which sets of model conditions can be considered as more realistic: those, under which menu costs lead to hysteresis, or those, under which they do not. In order to do this, different variants of the model are required to reproduce some important stylized empirical facts related to micro-level price changes. They are calibrated to match the most important moments of two empirical distributions related to product-level price adjustment, which stem from one of the most popular empirical samples containing observations about micro-level price changes, the Dominick's dataset,[6] which is often used for calibrating menu cost models (Midrigan 2011; Alvarez et al. 2016). The empirical relevance of the model variants is assessed by analyzing how well they are able to capture the key moments of the empirical distributions.

As the first result of the paper, it is shown that the presence of menu costs does lead to hysteresis in the simplest variants of the model. Then, the focus is turned to examining why it does not lead to hysteresis in DSGE-type menu cost models. Two crucial differences are identified between the simplest variants of the applied agent-based menu cost model and DSGE-type menu cost models, which may be responsible for their different implications regarding the emergence of hysteresis. On the one hand, firms are assumed to be boundedly rational in the spirit of post-Keynesian economics and of agent-based computational economics, while DSGE-type menu cost models contain perfectly rational, dynamically optimizing firms. A simple variant of the model with dynamically optimizing firms is built up, and it is found that hysteresis emerges in that model variant, as well.

On the other hand, firms are assumed to be hit by idiosyncratic productivity shocks in DSGE-type menu cost models. It is shown that once idiosyncratic productivity shocks are introduced to the model, menu costs do not lead to hysteresis anymore. Thus, these shocks are the reason why there is no hysteresis in DSGE-type menu cost models. Since they are necessary for the model to reproduce the large mean size of empirical price changes (Golosov – Lucas 2007), two conclusions are drawn:

[5] Bassi – Lang (2016) also apply an agent-based model to analyze hysteresis in real output.

[6] See Section 2 for details about the dataset.

1. It is possible to build theoretical models, in which menu costs lead to hysteresis, but according to our existing knowledge, they are not relevant empirically.
2. If one accepts that menu costs do not lead to hysteresis in aggregate output, one has to look for other types of economic mechanisms capable of explaining the potential hysteretic dynamics of empirical GDP. If one insists on the idea that hysteresis does emerge as a consequence of menu costs, then one has to replace the assumption about the arrival of idiosyncratic productivity shocks with another one, which is able to help the model fit to the empirical data at least as well as under idiosyncratic productivity shocks, and does not eliminate hysteresis in aggregate output. An interesting, but challenging way of future research is to find such an assumption.

Finally, it is pointed out that the result, according to which menu costs do not lead to hysteresis in the empirically most relevant variants of the model, does not imply that there exists no economic mechanism capable of generating hysteresis in aggregate output in an empirically relevant way. It is shown that the presence of demand-supply interactions (Arestis – Sawyer 2009), i.e., positive feedbacks from actual to potential real economic activity may do the trick. Such interactions between aggregate demand and aggregate supply may emerge as a result of any of the economic mechanisms mentioned earlier as being capable of generating hysteresis. They represent the other possible economic mechanism besides the presence of nonlinear price adjustment, which is capable of explaining the empirical evidence against long-run monetary neutrality according to post-Keynesian macroeconomists (Palacio-Vera 2005; Fontana – Palacio-Vera 2007; Kriesler – Lavoie 2007).[7]. The results presented in this paper suggest that the presence of demand-supply interactions can be considered as a more relevant explanation empirically, than the nonlinear nature of price adjustment.

The remainder of the paper is organized as follows. In Section 2, the micro-level dataset used to derive the empirical distributions related to price adjustment is presented, as well as the key properties of the distributions, which should be reproduced by the model. The agent-based menu cost model and its calibration are presented in Section 3. The conditions, under which menu costs do or do not lead to hysteresis in different variants of the model, are examined in Section 4. The role of demand-supply interactions in generating hysteresis is highlighted in Section 5. Section 6 concludes.

2. EMPIRICAL DATA

Before developing the agent-based menu cost model, it is important to summarize the stylized empirical facts that the model is required to reproduce. The empirical plausibility of different variants of the model will be assessed by analyzing how well they fit to the key moments of two empirical distributions concerning product-level price adjustment: the distribution of nonzero price changes and the distribution of the frequencies of price changes.

[7]The cited papers often identify demand-supply interactions – or demand-led growth – with hysteresis. However, it is useful to differentiate between the two terms, since hysteresis refers to a general property of a dynamic system, meaning that transitory shocks exert permanent effects on its steady state (Amable et al. 1993; Cross 1993; Göcke 2002). The possible economic mechanisms behind hysteresis include demand-supply interactions, but other types of economic mechanisms are also able to result in hysteretic macrodynamics.

These two empirical distributions are derived using a micro-level dataset, which is often applied for calibrating menu cost models, the so-called Dominick's dataset (Midrigan 2011; Alvarez et al. 2016). It consists of scanner price data collected by the James M. Kilts Center for Marketing of the University of Chicago Booth School of Business. The dataset contains 9 years (1989–1997) of weekly store-level data about the prices of more than 9,000 products collected in 86 stores of the Dominick's Finer Foods retail chain in the Chicago area. As prices are highly correlated across stores, Midrigan (2011) has decided to work with the prices of one single store, which has the largest number of observations. He has made the resulting dataset available in the Supplemental Material to his paper: this is the dataset that is applied in this article.

The model in Section 3 does not contain any incentives for firms to engage into temporary sales, therefore the data are sales-filtered in order to obtain time series about regular prices. The algorithm developed by Kehoe – Midrigan (2008) is used to filter out temporary sales.[8] The resulting weekly time series of regular prices are time-aggregated to monthly frequency by keeping every fourth observation of the time series only. The monthly frequency of the resulting sample is closer to the quarterly frequency of GDP data that will be used for estimating some parameters of the model. The sample consists of 100 months long time series of regular prices for 9,450 different products. For the sake of precaution, Midrigan's (2011) practice is followed, and only those price observations are kept, for which the calculated regular price is equal to the observed price. Finally, all nonzero regular price changes are calculated as the log-difference of subsequent monthly prices, and following Midrigan (2011), all regular price changes with a size greater than the 99th percentile of the size distribution of price changes are dropped in order to get rid of outliers. The final sample consists of 22,630 observations of nonzero monthly regular price changes.

The first step to derive the empirical distribution of the frequencies of price changes is to calculate the frequency of monthly regular price changes for each of the 9,450 products. This is done by dividing the number of months, in which the price of the product has changed with the total number of months, for which the price observation, as well as the observation of the previous month are non-missing. Then, all products, for which the calculated frequency is equal to 0, are dropped. The reason for this is that it seems unlikely that the price of a product does not change at all for 9 years, hence missing values are the most probable reason for not registering any price changes for these products. Finally, all products with a frequency of price changes greater than the 99th percentile of the frequency distribution are dropped in order to get rid of outliers.[9] The final sample consists of the frequencies of regular price changes for 7,765 products.

Figure 1 presents the two empirical distributions. Superimposed are the probability density functions of the normal distribution with equal means and variances. Graphical inspection of Figure 1 supplemented with the calculation of some key moments of the two distributions reveals some important stylized facts about price adjustment that the model should reproduce.

[8]The Matlab codes for the sales-filtering algorithm, as well as for calculating the moments of the empirical distribution of nonzero price changes are available in the Supplemental Material to Midrigan (2011). Appendix 1 of the same Supplemental Material describes the sales-filtering algorithm in detail.

[9]As the number of observations available to calculate the frequencies of price changes is different for each product, the price change frequency of every product is weighted with the number of observations available to calculate it while computing the percentiles of the frequency distribution.

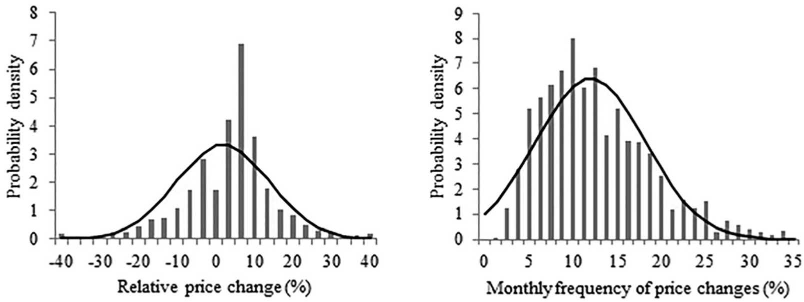

Fig. 1. **The empirical distributions of nonzero price changes (left panel) and of the frequencies of price changes (right panel)**
Note**: Both histograms are based on the data available in the Supplemental Material to Midrigan (2011).**

All price changes and all frequencies of price changes related to a certain product are weighted with the share of that product in the basket of the average customer of Dominick's while calculating the moments of the distributions.[10]

The stylized facts and the empirical values of the key moments are the following:[11]

1. *The mean size of price changes is large* (9.7%). The model obviously needs to reproduce this fact for the strength of price adjustment to be realistic.
2. *The standard deviation of price changes is large* (12.5%). This moment will be used to pin down the standard deviation of idiosyncratic productivity shocks in the model.
3. *Price changes are rare* for the average product. The mean monthly frequency of price changes is 11.6%. This moment is obviously important to be reproduced by the model in order to generate a realistic degree of price stickiness.
4. *The distribution of the frequencies of price changes is skewed to the right*: the skewness of the distribution is 0.62. This information will help the model generate a realistic degree of heterogeneity in the frequencies of price changes, which will play an important role in one of its variants.

3. THE AGENT-BASED MENU COST MODEL

In this section, the agent-based menu cost model and its calibration are presented. The goods market of an economy is modeled, the supply side of which consists of N monopolistically competitive firms, each of them selling one single product variety. All product varieties sold in the market are differentiated from each other.

[10]In case of the distribution of the frequencies of price changes, an additional weight is used in addition to the consumption shares for calculating its moments: the frequencies of price changes of different products are weighted with the number of observations available to calculate them, as it is different for each product because of the numerous missing values present in the dataset.

[11]These stylized facts can be considered as standard: they have all been reported before in the empirical literature of sticky price adjustment (Bils – Klenow 2004; Klenow – Kryvtsov 2008; Nakamura – Steinsson 2008).

3.1. The demand side of the market

The demand side of the market is assumed to consist of a perfectly rational representative household that behaves according to the Dixit – Stiglitz (1977) model of monopolistic competition.[12] The household decides about the demanded quantities of different product varieties in a way that maximizes its utility subject to its budget constraint:

$$\max_{\{c_{i,t}\}_{i=1}^{N}} C_t\left(c_{1,t},\ c_{2,t},\ \ldots,\ c_{N,t}\right) = \left(\sum\nolimits_{i=1}^{N} c_{i,t}^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}} \text{ s.t. } \sum\nolimits_{i=1}^{N} p_{i,t}c_{i,t} = Y_t,$$

where c stands for the consumed quantities and p stands for the prices. The i subscript refers to the firms, as well as to the product varieties they supply, and the t subscript stands for the time periods, which will be taken to a month during the calibration. C denotes the utility of the household, which will be used to measure aggregate consumption in the model. The utility function is assumed to be of a CES type (CES – *Constant Elasticity of Substitution*), where $\varepsilon>1$ is the absolute value of the elasticity of substitution between any two product varieties. Y denotes nominal aggregate demand, or equivalently, the nominal income of the representative household. The budget constraint expresses that total spending on different product varieties has to be equal to the household's nominal income.

By solving the household's utility-maximization problem, one can derive its demand functions for the N product varieties. The demand function for variety i is the following:

$$c_{i,t} = \left(\frac{p_{i,t}}{P_t}\right)^{-\varepsilon}\frac{Y_t}{P_t}, \tag{1}$$

where the price level in period t is given by the CES price index $P_t = \left(\sum\nolimits_{i=1}^{N} p_{i,t}^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$. The interpretation of demand function (1) is rather intuitive: the demanded quantity of a given product variety decreases *ceteris paribus*, if it becomes more expensive relative to the market price level. The second factor expresses that a rise in the household's real income increases the demanded quantities of all product varieties, assuming that their relative prices remain unchanged.

The household's nominal income is determined by the central bank's monetary policy. It is assumed that the central bank is able to control nominal aggregate demand perfectly according to an exogenous stochastic process.[13] Let g_t^Y denote the gross growth rate of nominal aggregate demand in period t, i.e., $g_t^Y = Y_t/Y_{t-1}$. Nominal aggregate demand is

[12]The assumption of a perfectly rational representative household is rather unusual in an agent-based economic model, but it substantially simplifies the technical details of the model without altering its core message, and it facilitates comparison with standard DSGE-type menu cost models. In menu cost models, the important nominal and real adjustments take place in the supply side of the market, therefore the demand side is usually modeled as simply as possible.

[13]The assumption that the central bank controls the household's nominal income directly is a shortcut for the usual practice followed in DSGE-type menu cost models, according to which the functional form of the utility function is chosen in a way, which assures that nominal income will be proportional to nominal money supply in case of optimal behaviour. See Golosov – Lucas (2007) for the necessary restrictions on the utility function.

assumed to be growth-stationary, i.e. its growth rate follows a first order autoregressive (AR (1)) process:[14]

$$\log g_t^Y = \varphi \log g_{t-1}^Y + \xi_t, \tag{2}$$

where $\varphi \in [0,\ 1)$ determines the persistence of nominal demand growth, and $\xi_t \sim N(0, \sigma_\xi^2)$ is an independent, identically normally distributed random variable with mean 0 and variance σ_ξ^2. ξ_t represents the value of the monetary shock in period t. Note that there is no constant in equation (2), which means that trend growth in nominal aggregate demand is assumed away for simplicity. This is equivalent to assuming that there is no trend inflation in the economy.

Y_t could also be labeled as the nominal money supply, if one assumed that the total money stock gets directly into the hands of the representative household. Nakamura and Steinsson (2010) also use the term *nominal aggregate demand* for Y_t.[15]

3.2. The supply side of the market

The supply side of the market is modeled differently than in the Dixit – Stiglitz (1977) model. At this point, the model's agent-based features start playing important roles. The supply side of the market is populated by N heterogeneous, monopolistically competitive firms: they are the agents in the model. Each firm is assumed to have a so-called *supply potential* $\overline{q}_{i,t}$, which is allowed to change over time. The supply potential can be interpreted as the optimal scale of production, the amount of output corresponding to the optimal plant size, the produced quantity corresponding to the normal rate of capacity utilization, or as some kind of a micro-level potential output.[16] Firms try to set their prices in a way that equalizes demand for their products with their supply potentials. If their products are produced in quantities different from their supply potentials, then they suffer losses compared to the maximal attainable amount of profits.

It is assumed in line with the views of Simon (1972), with the perspective of post-Keynesian economics (Lavoie 2014), with the spirit of agent-based computational economics (Tesfatsion 2006; Dosi 2012; Fagiolo – Roventini 2017) and with the experimental evidence of behavioural economics (Tversky – Kahneman 1974; Camerer et al. 2004) that firms are boundedly rational. Boundedly rational decision-making is interpreted according to Simon (1972): as firms are not perfectly informed about the market environment because of its complexity, and as the cognitive abilities of their decision-makers are limited, they are not able to make optimal decisions. Instead, they use heuristics, i.e., simple *rules of thumb* for decision-making. Heuristics make it possible for firms to easily arrive at decisions that are in accordance with their profit-maximizing motivations by simplifying the decision problem (Gigerenzer 2008; Hommes 2013). In this sense, the decisions made are satisfying, but not optimal.

[14]The same AR(1) process is assumed for nominal money growth in the menu cost models of Midrigan (2011) and Karádi – Reiff (2019). In case of the latter, the right-hand side of the equation contains an additional constant term, since it is assumed that there is trend inflation in the economy.

[15]The assumption, according to which the central bank is able to control nominal aggregate demand through equation (2) can be justified by a model of demand, in which nominal aggregate demand is proportional to nominal money supply, and the central bank follows a money growth rule (Nakamura – Steinsson 2010).

[16]The term *supply potential* is borrowed from Arestis – Sawyer (2009).

During their price decisions, firms pay attention to the excess demand/supply that they anticipate for their products. It is assumed that production is demand-determined, thus produced quantities $q_{i,t}$ are equal to demanded quantities: $q_{i,t} = c_{i,t}$ for $\forall i, t$. Before making their price decisions, firms form expectations about the excess demand $\widehat{q}_{i,t}$ for their supplied products by computing the relative deviations between the anticipated quantities of their demand-determined output and their supply potentials:

$$\widehat{q}^{e}_{i,t} = \frac{q^{e}_{i,t} - \overline{q}_{i,t}}{\overline{q}_{i,t}},$$

where x^e denotes the firm's expectation for the value of any variable x.

The heuristic price decision rule applied by the firms is in accordance with their motivation to produce close to the supply potentials of their products, as it helps coordinating demand with them.[17] The presence of menu costs implies that it is not worth changing the price, if the anticipated demanded quantity of the firm's product is close to its supply potential, since the loss implied by the menu cost would probably offset the potential gains of price adjustment. This consideration leads to the emergence of an inaction band around the supply potential, within which the firm keeps its price unchanged. Let z_i denote the price adjustment threshold of firm i, i.e., the anticipated absolute excess demand for its product, above which it changes the price. This threshold value is allowed to be heterogeneous across firms, e.g., because firms are different with respect to the amount of menu costs they face.[18]

The heuristic price decision rule can be written as:

$$p_{i,t} = \begin{cases} p_{i,t-1}\left(\dfrac{q^{e}_{i,t}}{\overline{q}_{i,t}}\right)^{\alpha}, & \text{if } \left|\widehat{q}^{e}_{i,t}\right| > z_i \\ p_{i,t-1}, & \text{if } \left|\widehat{q}^{e}_{i,t}\right| \leq z_i \end{cases}, \tag{3}$$

where $\alpha \in [0,\ 1]$ is a parameter determining the strength of price adjustment. According to price decision rule (3), firms keep their prices unchanged, if the anticipated excess demand/supply for their products does not exceed their price adjustment thresholds. In the opposite case, they adjust their prices based on the anticipated excess demand/supply. If firm i expects demand for its product to be greater than its supply potential, then it will raise the price in order to decrease demanded quantity. In the opposite case, the firm will lower the price with the intention to

[17]According to survey data from the U.K., 65% of the surveyed firms set their prices using rules of thumb, or on the basis of past or current information primarily. Only 35% of the surveyed firms claim that they set their prices in a forward-looking way (Greenslade – Parker 2012).

[18]The value of z_i is not determined by menu costs alone: it may also depend e.g., on the time preferences of the firm's decision-makers, or on their perceptions about the uncertainty of the market environment. Nevertheless, the price adjustment threshold would not exist, if firms faced no menu costs associated with their price changes, and it is reasonable to assume that the threshold depends positively on the amount of menu costs to be paid. As it has been mentioned in the *Introduction*, the lack of decreasing returns near the supply potential is an alternative explanation for the existence of a price adjustment threshold.

increase demanded quantity, bringing it closer to the supply potential. The size of the price change is regulated by parameter α.[19]

The individual price adjustment thresholds are drawn from a lognormal distribution, which is an asymmetric probability distribution, hence it allows the model to reproduce stylized fact 4, according to which the frequency distribution of price changes is skewed to the right. Specifically, it is assumed that

$$\log z_i \sim N\left(\log\left(\frac{\overline{z}^2}{\sqrt{\overline{z}^2+\sigma_z^2}}\right), \log\left(\frac{\overline{z}^2+\sigma_z^2}{\overline{z}^2}\right)\right),$$

where $\overline{z}>0$ and $\sigma_z>0$ are parameters. The above parameterization of the normal distribution assures that the mean price adjustment threshold is exactly equal to $\overline{z}$ and the standard deviation of price adjustment thresholds equals σ_z.

Firms are assumed to use a very simple adaptive rule to form their expectations about demand for their products. They expect that demanded quantity in the current period will be equal to the quantity demanded in the previous period:[20]

$$q^e_{i,t} = q_{i,t-1}.$$

The evolution of supply potentials is determined by two stochastic processes. It is assumed that the supply potential of the good produced by firm i in period t can be decomposed into two components as:

$$\overline{q}_{i,t} = \mu_t \cdot \delta_{i,t},$$

where μ_t is the aggregate component of the supply potential, which is common to all product varieties supplied in the market, and $\delta_{i,t}$ is the firm-specific component of the supply potential, which is independent across firms, but is correlated in time.

Let $g^\mu_t = \mu_t/\mu_{t-1}$ denote the gross growth rate of the aggregate component. Its evolution is assumed to be determined by the following stochastic process:

$$\log g^\mu_t = \eta\left(\log Q_{t-1} - \log \overline{Q}_{t-1}\right), \tag{4}$$

where $Q_t = \left(\sum_{i=1}^N q_{i,t}^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}}$ is the real aggregate output of the economy computed as the CES aggregate of individual produced quantities, and $\overline{Q}_t = \left(\sum_{i=1}^N \overline{q}_{i,t}^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}}$ is the potential output of

[19]The assumed price decision rule conditional on adjustment is inspired by Kornai – Martos (1973), who assume that firms decide about production on the basis of excess demand, which is proxied by the difference between the actual and the desired amount of their inventories. Duménil – Lévy (1991) assume the same decision rule for prices. In agent-based models, it is also standard to assume that prices or markups react to excess demand either directly (Leijonhufvud 2006; Guerini et al. 2018), or indirectly through the deviation of the actual amount of inventories from the desired one (Lengnick 2013; Gaffeo et al. 2015).

[20]Gigerenzer – Brighton (2009) argue that the simplest heuristics are more successful in fundamentally uncertain environments than more sophisticated ones. Dosi et al. (2020) examine this idea within the context of an agent-based macroeconomic model, and find that the simple adaptive rule that is assumed in this paper for forming demand expectations beats the forecasting performance of more sophisticated rules, like least squares learning.

the economy calculated as the CES aggregate of individual supply potentials. $\eta \in [0, 1]$ is a parameter determining the strength of demand-supply interactions in the economy.

Equation (4) can be interpreted as follows. If the actual output of the economy equals its potential output, then the aggregate component of supply potentials does not change, i.e., potential growth is assumed away in steady state. If the output gap is positive ($Q_t > \overline{Q}_t$), then the potential growth rate rises above zero. If the output gap is negative ($Q_t < \overline{Q}_t$), then the potential growth rate falls below zero. The strength of this interaction between actual and potential output is regulated by parameter η.[21] Some examples for the potential economic mechanisms underlying these demand-supply interactions have been mentioned in the *Introduction*. Demand-supply interactions are assumed to take place between *aggregate* actual and potential output at the macro level of the economy, and not at the micro level.[22] On the one hand, this allows one to estimate η using macroeconomic data instead of micro-level observations. On the other hand, it seems reasonable to assume that a recessionary macroeconomic environment worsens the growth prospects for *all* firms, not just for those that are forced to produce below the supply potentials of their products. As it has been mentioned in the *Introduction*, long-term unemployment increases during recessions, the quality and the quantity of the active labor force deteriorates, which is an aggregate effect, reducing the opportunities of all firms to hire workers with sufficiently strong skills. Aggregate productivity growth slows down during recessions, making it more difficult for all firms to benefit from knowledge spillovers, etc.

Just like in DSGE-type menu cost models (Golosov – Lucas 2007; Nakamura – Steinsson 2010; Midrigan 2011; Alvarez et al. 2016; Karádi – Reiff 2019), the firm-specific component of the supply potential is assumed to be hit by idiosyncratic productivity shocks. Its evolution is determined by the following stochastic process:

$$\log\delta_{i,t} = \rho\log\delta_{i,t-1} + \zeta_{i,t},$$

where $\zeta_{i,t} \sim N(0, \sigma_\zeta^2)$ is an independent, identically normally distributed random variable with mean 0 and variance σ_ζ^2, which represents the idiosyncratic productivity shock hitting the supply potential of firm i in period t, and $\rho \in [0, 1)$ is a parameter determining the persistence of idiosyncratic productivity shocks.

3.3. Simulations

The nonlinearities and the different forms of heterogeneity present in the model do not allow for an analytical solution, hence its behaviour is analyzed using computer simulations. Simulations are started from a situation, in which the market is not hit by either aggregate, or idiosyncratic shocks, the actual quantities produced are equal to the supply potentials, and all variables are constant in time. The initial values of supply potentials are set to $\overline{q}_{i,0} = 1$ for $\forall i$, and the initial

[21] DeLong – Summers (2012) model demand-supply interactions with the same equation. Similar ways of modeling demand-supply interactions can be found in the post-Keynesian literature (Fontana – Palacio-Vera 2007; Kriesler – Lavoie 2007; Setterfield 2009), while Jorda et al. (2020) model endogenous TFP growth similarly in a DSGE framework.

[22] However, it is possible to come up with microeconomic foundations for the macro-level relationship represented by equation (4). Dosi et al. (2010) do it in an agent-based macro model with boundedly rational firms, while Anzoategui et al. (2019) and Garga – Singh (2021) come up with perfectly rational, optimizing microfoundations within DSGE frameworks.

value of nominal aggregate demand is set to $Y_0 = N$. This implies that nominal demand per product variety is equal to 1, and prices also need to be equal to 1 initially. First, simulations are run for 1,000 periods: this amount of simulation time is enough for a steady state joint distribution of relative prices and supply potentials to emerge. Then, simulations are run for another T periods, and the first 1,000 periods are discarded. This way, it is assured that the statistics computed from the simulated time series will not be biased by the initial adjustment towards a steady state.

In case of simulating impulse response functions to monetary shocks, a similar procedure is followed. First, a $1000 + T$ period long baseline path is simulated for the variables without monetary shocks, but with the presence of idiosyncratic productivity shocks. Then, another path is simulated using the same random numbers, but with a monetary shock of a given size arriving in period 1,002. The percentage deviations between the two simulated paths of the variables are calculated, the first 1,000 periods are discarded, and period 1,001 is treated as period 0. This exercise is repeated 10,000 times, and the 10,000 time series are averaged out for each variable. The resulting time series approximate the conditional expectations for the deviations between the values of the variables on the baseline paths and on the paths hit by the monetary shock, where there are two conditions:

1. The variables are forecasted from period 0, when the market is in steady state.
2. The central bank generates a monetary shock of a given size in period 1, and sets $\xi_t = 0$ for $\forall t > 1$.

The resulting conditional forecasts are the impulse response functions of the variables of interest.[23] This way, it will become possible to assess, if a particular transitory shock to the growth rate of nominal aggregate demand interacting with the idiosyncratic productivity shocks that are expected to arrive, while the monetary shock dies away, has a permanent effect on the level of real output in expectation, or not. If it has, then hysteresis can be observed in the model.

3.4. Calibration

There are some parameters in the model, which are assigned values to before carrying out the calibration exercises. The length of the simulations (T) and the number of firms (N) are chosen to be as large as it is tolerable from the point of view of the computational burden. Specifically, T is set to 10,000 and the number of firms N is set to 1,000. Following Midrigan (2011), the elasticity of substitution ε between different product varieties is set to 3.[24]

Nominal aggregate demand is measured by nominal GDP. Its time series is seasonally adjusted, and its source is the U.S. Bureau of Economic Analysis.[25] As the two empirical distributions characterizing micro-level price adjustment are based on a dataset that has been aggregated to monthly frequency, a period in the model should correspond to a month, hence

[23]Koop et al. (1996) explain in detail why this is the appropriate way of simulating impulse response functions in nonlinear multivariate models.

[24]Midrigan (2011) comes up with this value on the basis of existing empirical estimates about the elasticity of substitution in grocery stores similar to Dominick's.

[25]The data are downloaded from the FRED database of the Federal Reserve Bank of St. Louis.

the parameters of stochastic process (2) governing nominal aggregate demand should also be estimated using monthly data. Unfortunately, the highest frequency, at which GDP data are available, is quarterly. Therefore, quadratic spline interpolation is used to approximate the possible monthly time series of nominal GDP. The estimates are based on this interpolated sample that covers all months between January 1989 and December 1997 (108 observations altogether), which is the same time period, during which the Dominick's dataset has been collected. The two parameters of stochastic process (2) are estimated by fitting an AR(1) process on the monthly growth rate of U.S. nominal GDP without a constant term. The persistence of nominal demand growth φ is estimated to be 0.93 and the standard deviation of monetary shocks σ_ξ is estimated to be 0.0017.

There is no consensus in the literature about the value of parameter ρ that determines the persistence of idiosyncratic productivity shocks hitting supply potentials. Following Costain – Nakov (2011) and Karádi – Reiff (2012), its value is set to 0.95, which leads to highly persistent idiosyncratic productivity shocks.

The rest of the parameters is calibrated in order to allow variants of the model to match some important moments of the two empirical distributions related to micro-level price adjustment.[26] Grazzini – Richiardi (2015) argue that among the standard methods used for estimating the parameters of DSGE models, the simulated method of moments (SMM) is the easiest to apply in an agent-based framework. Therefore, the parameters of the model variants are calibrated using SMM. According to the central idea of SMM, the estimated combination of parameters is the one that minimizes the average distance between some moments simulated by the model and their empirical counterparts.[27] In particular, the unweighted sum of squared log-deviations between the simulated and the empirical values of the moments is used as a criterion function to be minimized.[28] During the calibration exercises, simulations are run using equation (2), i.e. with a monetary shock arriving in each period. The estimated parameter values for each model variant can be found in *Table 4* of the working paper version of this article (Váry 2020).

4. THE MAIN RESULTS

4.1. The basic model variants

In this section, the agent-based menu cost model presented in Section 3 is used to examine whether it is possible to create such sets of conditions within its framework, under which the presence of menu costs results in hysteresis in aggregate output. In the first step, an extremely simplified variant of the model is considered, and new features will be added to it step by step in order to make it clear, which features are responsible for the presence or for the absence of hysteresis.

The starting point of the analysis is the benchmark model variant labeled as Variant A0. In Variant A0, firms are homogeneous in all respects, demand-supply interactions are assumed

[26]The values and the importance of these moments have been described in Section 2.

[27]See e.g., Adda – Cooper (2003) for a didactic description about the simulated method of moments.

[28]In case of moments, the values of which are allowed to be negative, the log-deviations between the simulated and the empirical values of the moments are substituted with their relative deviations.

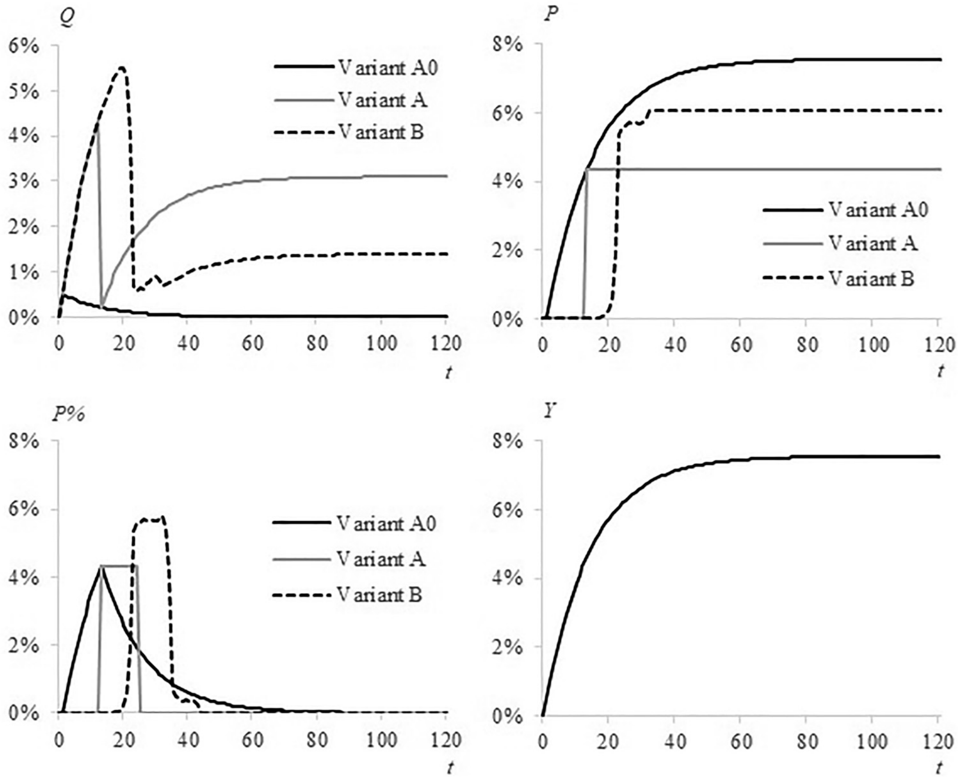

Fig. 2. **The impulse responses of *Q*, *P*, *P*%, and the level of *Y* to a three-standard deviation positive transitory shock to the growth rate of *Y* in Model Variants A0, A, and B**
***Note*: *Q* = Real aggregate output, *P* = Price level, *P*% = Inflation rate, *Y* = Nominal aggregate demand.**

away, and firms are not hit by idiosyncratic productivity shocks, hence the supply potentials are constant in time. Most importantly, price adjustment is free, there are no menu costs to pay.

The impulse response of this simple model variant to a three standard deviation monetary shock is presented on Figure 2.[29] Inflation is denoted by *P*% on the figure, and it is measured by the year-on-year growth rate of the price level. On impact, the monetary shock increases the purchasing power of the household, hence demand increases for all product varieties in the market. It can be seen in Figure 2 that real aggregate output is slightly increased in the short run even in the absence of menu costs. The reason for this is the bounded rationality of firms, because of which they are not able to react to the shock optimally in the short run, hence their actual amounts of output increase above their supply potentials. But in the long run, they react

[29]The model variant is hit with an atypically large, three standard deviation monetary shock, because under the applied calibration, a one or a two standard deviation shock would not be sufficiently large in Model Variant B to induce any firms to change their prices.

to the excess demand by increasing their prices. This reduces the household's purchasing power back to its initial level, hence real aggregate demand and output return to their initial steady state values, which means that the dynamics of aggregate output is not hysteretic in the absence of menu costs.

Hysteresis emerges in Variant A, which is the extension of Variant A0 with menu costs. Firms are still homogeneous in all respects, but they have to face menu costs when changing their prices, hence the price adjustment thresholds are positive. The economic mechanism behind the observed impulse response of Variant A is the following. In the first few periods, the rise in nominal aggregate demand fully transforms into real output growth, as the presence of menu costs implies that firms do not react to small deviations between demand and the supply potential by changing their prices. But as demand gets too far away from the supply potential, firms become willing to pay the menu cost, and they increase their prices. Real output falls as a consequence, but immediately starts rising again as nominal aggregate demand increases further. This time, actual output does not get far enough from the supply potential to make firms willing to pay the menu cost once more. Hence, prices do not increase anymore, and the level of real aggregate demand becomes permanently higher as nominal aggregate demand settles down at its new, higher steady-state level. Consequently, the quantities of all product varieties are permanently greater in the new steady state than in the initial one. This means that a transitory shock to the growth rate of nominal aggregate demand has a permanent effect on the level of real aggregate output, thus hysteresis emerges in this simple model variant.

A drawback of Variant A is that discrete jumps can be observed in real output and in the price level, which may be realistic at the micro-level, but not at the macro-level of the economy. The impulse response functions can be made continuous, if firms are assumed to be heterogeneous with respect to their price adjustment thresholds. This idea stems from the models of strong hysteresis, in which the aggregation of heterogeneous discontinuous micro-level adjustments to exogenous shocks leads to continuous nonlinear adjustment at the macro level (Amable et al. 1993, 1994; Cross 1994; Göcke 2002; Setterfield 2009). The assumption is justified by the stylized empirical fact presented on the right panel of Figure 1, according to which there is substantial heterogeneity in the frequencies of price changes of different products. Model Variant B is the extension of Variant A with heterogeneous price adjustment thresholds. Hysteresis is present in this model variant, as well, but the discrete jumps have disappeared from the impulse response functions. The reason for this is that now, individual firms adjust their prices in response to the monetary shock in different time periods, and not at the same time.

The impulse response functions presented on Figure 2 make it clear: the presence of menu costs leads to hysteresis in aggregate output in the basic model variants. This is in line with the results of Delgado (1991) and Dixit (1991), but it raises an important question: why is there no hysteresis in DSGE-type menu cost models (Golosov – Lucas 2007; Nakamura – Steinsson 2010; Midrigan 2011; Alvarez et al. 2016; Karádi – Reiff 2019)? DSGE-type menu cost models contain two key assumptions that the basic model variants presented in this subsection do not, and might potentially eliminate hysteresis:

1. *Dynamic optimization*: Firms are perfectly rational instead of being boundedly rational. They decide about the optimal prices by solving a dynamic optimization problem.

2. *Idiosyncratic productivity shocks*: Besides the monetary shock, which is an aggregate shock affecting all firms, firms are hit by idiosyncratic productivity shocks, as well.

In the next two subsections, these two features are introduced into Model Variant A separately, and their effects on the emergence of hysteresis are studied. For simplicity, firms are assumed to be homogeneous with respect to their price adjustment thresholds.

4.2. Dynamic optimization

Let us first turn to the assumption of perfectly rational firms that decide about their prices by dynamic optimization. It can be noticed in Figure 2 that the quantities produced deviate permanently from the supply potentials in the new steady state of Model Variant A, causing infinitely big losses for firms in the long run compared to the maximal attainable profit stream under flexible prices. A forward-looking firm may notice this, and may be willing to pay the finite menu cost in the present in order to avoid the infinitely big, expected future loss. Thus, it may revert the price back to its flexible-price steady-state level, eliminating hysteresis.

Model Variant C is the same as Variant A except of one important difference: firms are perfectly rational instead of being boundedly rational. Instead of using heuristic price decision rule (3), they decide about their prices by dynamic optimization. Firms are assumed to be perfectly informed about the structure of the market, i.e. they know demand function (1), AR(1) process (2) governing the growth rate of nominal aggregate demand, as well as the fact that the supply potentials and the menu costs of their competitors are the same as theirs. These simplifying assumptions imply that all firms always set the same price, hence it is sufficient to study the decision problem of one single representative firm. Therefore, it is not necessary to use subscript i to distinguish between different firms in the remainder of this subsection.

If all firms set the same price, i.e., $p_{i,t} = p_t$ for $\forall i$, then the CES price index becomes:

$$P_t = N^{\frac{1}{1-\varepsilon}} \cdot p_t.$$

Substituting this into equation (1), the demand function simplifies to:

$$c_t = \frac{Y_t}{Np_t}. \tag{5}$$

Production is still assumed to be determined by demand, thus $c_t = q_t$ for $\forall t$.

Perfectly rational firms maximize their values, i.e., the present values of their expected streams of profits on an infinite horizon. The profit function of the representative firm is assumed to be the following:

$$\pi_t = \overline{\pi} - \left(\frac{q_t - \overline{q}}{\overline{q}}\right)^2 - \tilde{z} \cdot I(p_t \neq p_{t-1}), \tag{6}$$

where π is the amount of profits earned by the firm, $\overline{\pi}$ is the maximal attainable profit level, i.e. the amount of profits under flexible prices, $\tilde{z}$ is the menu cost, which is not the same as the price adjustment threshold z in price decision rule (3), and $I(\ )$ is the indicator function, which returns the value of 1, if the firm changes the price, and it returns the value of 0, if the firm keeps the price unchanged.[30]

Profit function (6) expresses that the firm earns the maximal $\overline{\pi}$ amount of profits, if its output is equal to its supply potential, and it does not change the price, hence it does not have to pay the menu cost. The larger the relative difference between output and the supply potential, the less profits are earned. The deviation can be of any direction: if output is lower than the supply potential, then the firm will not earn as much revenues as it would in case of producing at the level of the supply potential. If output is higher than the supply potential, then the firm will have to overuse its capacities, causing its costs to rise by too much, implying a smaller amount of profits compared to $\overline{\pi}$. Besides the deviation of output from the supply potential, the menu cost also decreases the amount of profits in case of a price change.

In order to make the firm's dynamic profit maximization problem solvable, it has to be formulated in terms of stationary variables. The decision variable of the firm is the price, but as nominal aggregate demand is not stationary, the price will not be stationary, either. Therefore, output is used as the control variable, since its stationarity is assured by the constancy of the supply potential, which serves as a *center of gravity* for actual output. Of course, the firm does not decide about its output directly, but demand function (5) represents a one-to-one relationship between the price and the output, hence the choice of output unambiguously determines the price to choose, as well. As the dynamic optimization problem of the firm is now stationary, time indices are dropped in order to simplify the notation.[31] In the rest of this subsection, primes will indicate the values of the variables in the next period.

The value of changing the price can be written as:

$$V^C\left(g^Y\right) = \max_q \left\{ \overline{\pi} - \left(\frac{q-\overline{q}}{\overline{q}}\right)^2 - \tilde{z} + \beta \mathbb{E}_{g^{Y'}|g^Y} V\left(q, g^{Y'}\right) \right\}, \tag{7}$$

where $V^C(g^Y)$ is the value of changing the price, which is a function of only one state variable, the gross growth rate of nominal aggregate demand. $\beta \in (0,\ 1)$ denotes the discount factor, $V(q, g^{Y'})$ is the value of the firm in the next period and $\mathbb{E}_{g^{Y'}|g^Y}$ is the conditional expected value operator, where the expected value is calculated conditional on the nominal demand growth of the current period.

For formulating the value of not changing the price, it has to be determined what the output of the firm will be equal to in that case. Let q^{pre}, p^{pre} and Y^{pre} denote the values of output, the price and nominal aggregate demand in the previous period, respectively. If the firm does not change the price, then $p = p^{pre}$. It is also known that $Y = Y^{pre} \cdot g^Y$ by definition. Using these relationships, demand function (5) and the assumption of demand-determined output, the output in case of not changing the price can be written as:

[30] A similar formula is often used in simple menu cost models to approximate the true profit function. However, the quadratic loss is usually expressed as a function of the difference between the price and its desired value, and not as a function of the difference between output and its desired value as in equation (6) (Dixit 1991; Ball – Mankiw 1994; Karádi – Reiff 2019). Such a formula can be derived as a second-order approximation of the true profit function (Alvarez et al. 2016).

[31] It can be done, as the firm solves an infinite-horizon optimization problem of the same structure in each period.

$$q = \frac{Y}{Np} = \frac{Y^{pre} \cdot g^Y}{Np^{pre}} = q^{pre} \cdot g^Y.$$

Substituting this into profit function (6) and using the fact that no menu cost has to be paid, if the firm keeps the price unchanged, the value of not changing the price can be formulated as:

$$V^{NC}\left(q^{pre}, g^Y\right) = \overline{\pi} - \left(\frac{q^{pre} \cdot g^Y - \overline{q}}{\overline{q}}\right)^2 + \beta \mathbb{E}_{g^{Y'}|g^Y} V\left(q^{pre} \cdot g^Y, g^{Y'}\right), \tag{8}$$

where $V^{NC}(q^{pre}, g^Y)$ is the value of not changing the price, which is a function of two state variables: previous-period output and the gross growth rate of nominal aggregate demand.

The value of the firm is the maximum of the values of changing and not changing the price:

$$V\left(q^{pre}, g^Y\right) = \max_{\{C,\ NC\}} \left\{V^C\left(g^Y\right), V^{NC}\left(q^{pre}, g^Y\right)\right\}. \tag{9}$$

Equations (7), (8), and (9) constitute a system of Bellman equations. This system is solved numerically, using value function iteration on a grid. AR(1) process (2) of nominal demand growth is approximated with a 101-state Markov chain using a modified version of Tauchen's (1986) method described by Adda – Cooper (2003). Along the dimension of the other state variable, previous-period output, the grid consists of 501 elements, and the grid points are equidistantly spaced within the ±25% environment of the flexible-price steady-state output. The same set of values is used to approximate the control space of current period output. The solution of the (7–9) system of functional equations equips one with the value functions and the policy function of output. For evaluating the value functions and the policy function between and outside of the grid points, cubic spline interpolation is used during the value function iteration and the simulations. The optimal amount of output can be obtained directly from the policy function, while the optimal price is calculated from demand function (5) given the value of optimal output and using the assumption that output is equal to consumption.[32]

Following Midrigan (2011), the value of the annual discount factor is set to 0.96, which is consistent with a 4.2% annual interest rate. This implies that the value of the monthly discount factor β has to be $0.96^{1/12} = 0.997$. The maximal amount of profits $\overline{\pi}$ is normalized to 1. The value of the menu cost $\tilde{z}$ is estimated by SMM to match the mean frequency of price changes in the empirical data. It turns out to be 0.0013.

The impulse responses of Model Variants A and C to a two standard deviation positive monetary shock can be compared with the help of Figure 3.[33] Despite the preliminary expectations, the assumption of dynamically optimizing firms does *not* eliminate hysteresis in Variant C. The reason for this is that firms discount their expected future streams of profits during their price decisions. Firms have to suffer infinitely big losses in the long run compared to the maximal expected profit stream under flexible prices, since their output deviates permanently from their

[32]Further technical details about the solution method and the resulting policy function can be found in Appendix D of the working paper version of this article (Váry 2020).

[33]A one standard deviation shock is not large enough to induce firms in Model Variant A to change their prices. A two standard deviation shock is atypically, but not unrealistically large.

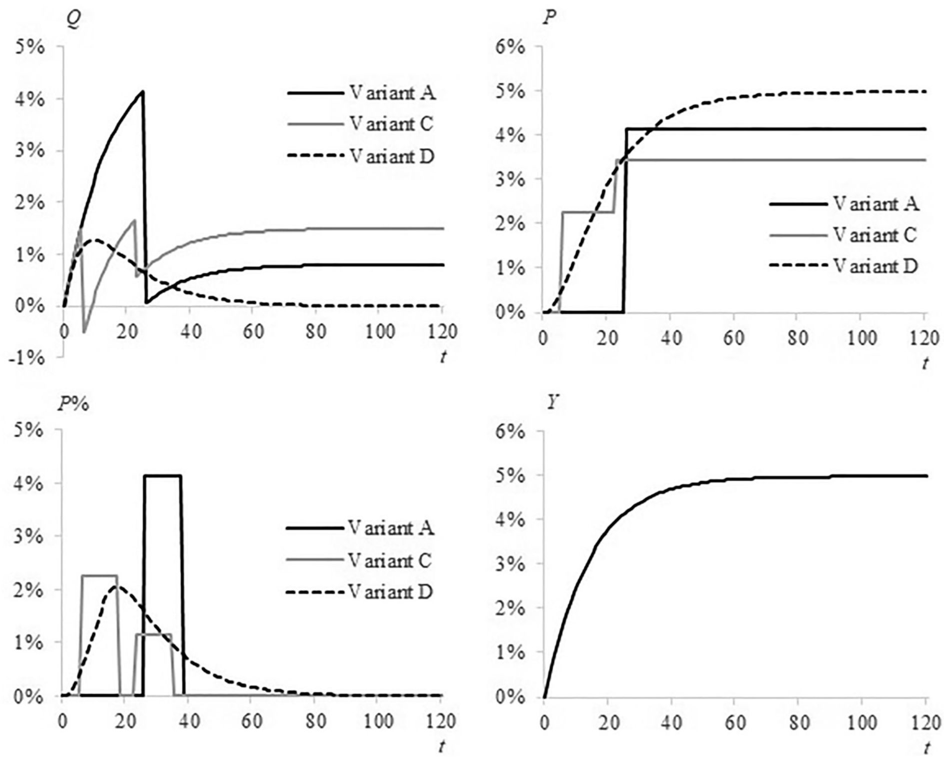

Fig. 3. **The impulse responses of of *Q*, *P*, *P*%, and the level of *Y* to a two standard deviation positive transitory shock to the growth rate of *Y* in Model Variants A, C, and D**
***Note*: *Q* = Real aggregate output, *P* = Price level, *P*% = Inflation rate, *Y* = Nominal aggregate demand.**

supply potentials after nominal aggregate demand has settled down at its new steady-state level. But after discounting, the present value of these losses becomes finite. Therefore, if the difference between actual output and the supply potential is not too big, it is not optimal to pay the finite menu cost in the present in order to avoid expected losses in the distant future that may not even realize at all. This means that the assumption of dynamically optimizing firms cannot be the reason why there is no hysteresis in DSGE-type menu cost models.

4.3. Idiosyncratic productivity shocks

Let us turn to the other standard assumption of DSGE-type menu cost models, according to which firms are hit by idiosyncratic productivity shocks at the micro level. Model Variant D is another extension of Variant A: firms are boundedly rational again, but now, their supply potentials are hit by idiosyncratic productivity shocks in each period.

The impulse response of Variant D to a two standard deviation positive monetary shock can also be seen in Figure 3. It is unambiguous that the introduction of idiosyncratic productivity shocks *does* actually eliminate hysteresis. Firms are expected to be hit by productivity shocks at the micro level, while nominal aggregate demand converges to its new steady-state value. Sooner or later, each firm is expected to face an idiosyncratic shock that is large enough to push its supply potential sufficiently far away from anticipated demand to make it worth changing the price. Thus, idiosyncratic productivity shocks are expected to force firms to adjust to the monetary shock perfectly in the long run by changing their prices, hence reverting real aggregate output back to its initial steady-state value and eliminating hysteresis.

The results presented in this section make it clear that the reason why there is no hysteresis in DSGE-type menu cost models is that the menu cost assumption is complemented with another key assumption, according to which firms are hit by idiosyncratic productivity shocks. The results have also provided an answer to the question why the menu cost models of Delgado (1991) and Dixit (1991) do produce hysteresis: although they contain dynamically optimizing firms, these firms are not assumed to be hit by idiosyncratic productivity shocks.

4.4. Empirical evaluation

So far, three model variants have been presented, in which menu costs lead to hysteresis in aggregate output, and one, in which they do not. If one would like to find out whether hysteresis generated by menu costs is an empirically relevant economic phenomenon, one has to assess how the different model variants fit to the most important moments of the two empirical distributions related to micro-level price adjustment.

Table 1 presents the values of these moments in the empirical data, as well as in different variants of the model. It can be seen that Model Variants A0, A, and B are too simple to be able to match even those moments that have been targeted during the SMM estimation, not mentioning the non-targeted ones. Variant C matches the targeted moment – the mean frequency of price changes – perfectly, but just like Variants A0, A, and B, it suffers from the usual weakness of menu cost models without idiosyncratic productivity shocks: it produces too small price changes. Variant D fits to the mean frequency of price changes perfectly, and it does a satisfying job in matching the mean size and the standard deviation of price changes, as well, thanks to the introduction of idiosyncratic productivity shocks.

Table 1. The values of targeted and non-targeted moments in the empirical data and in the data simulated by the model variants

Moment/Model Variant	Data	A0	A	B	C	D	E
Distribution of nonzero price changes							
Mean size (%)	9.7	*0.4*	*4.5*	*5.2*	3.1	*10.9*	*10.9*
Standard deviation (% points)	12.5	0.5	4.5	5.3	3.2	*11.1*	*11.1*
Distribution of the frequencies of price changes							
Mean (%)	11.6	100	*5.8*	*7.5*	*11.6*	*11.6*	*11.6*
Skewness	0.62	-	-	*0.78*	-	0.09	−0.02

Note: The moments targeted during the calibration of a particular model variant are italicied.

It can be concluded that idiosyncratic productivity shocks seem to be key ingredients of a menu cost model, since the empirical performance of Variant D has made it clear that they are necessary for the model to reproduce the large mean size of empirical price changes. The importance of idiosyncratic productivity shocks is stressed by numerous empirical studies, as well, according to which most of the variation observed in firm- or plant-level productivity is due to idiosyncratic factors (Bergoeing et al. 2003; Ábrahám – White 2006; Castro et al. 2015). If idiosyncratic productivity shocks are present in a menu cost model, then menu costs do not lead to hysteresis in aggregate output. Thus, it is concluded that theoretically, it is possible to build models, in which the presence of menu costs leads to hysteresis in aggregate output, but their empirical relevance seems to be ambiguous according to our existing knowledge.

There are two ways to proceed from this point, if one would like to explain the potential hysteretic nature of the dynamics of real aggregate output:

1. If one is convinced by the results of this subsection that menu costs are not able to lead to hysteresis in aggregate output, then one has to come up with another economic mechanism that is able to.
2. If one insists on the importance of menu costs in explaining hysteresis in aggregate output, then one has to find a new assumption to replace idiosyncratic productivity shocks in menu cost models, which allows the models to fit to the empirical distributions related to micro-level price adjustment at least as well as under idiosyncratic productivity shocks, while allowing menu costs to lead to hysteresis at the same time.

The second way seems to be quite challenging, but the possibility of following the first way is highlighted in Section 5.

5. HYSTERESIS UNDER DEMAND-SUPPLY INTERACTIONS

According to post-Keynesian economists, there is another economic mechanism besides the nonlinear nature of price adjustment, which is able to explain the empirical evidence against long-run monetary neutrality: the presence of demand-supply interactions in the economy (Palacio-Vera 2005; Fontana – Palacio-Vera 2007; Kriesler – Lavoie 2007). These interactions are already known to be able to generate hysteresis in aggregate output, and they are represented by equation (4) in the model, according to which a positive (negative) output gap affects the potential growth rate positively (negatively). In this section, it is highlighted that demand-supply interactions lead to hysteresis in aggregate output within the framework of the agent-based menu cost model, as well, even in the presence of idiosyncratic productivity shocks.

The assumptions about the presence of menu costs and idiosyncratic productivity shocks are maintained, as the results of Section 4 have made it clear that they are necessary for the model to reproduce the mean frequency and the mean size of empirical price changes. Based on the impulse response produced by Model Variant D, one can be sure that if a model variant with menu costs, idiosyncratic productivity shocks, and demand-supply interactions generates hysteresis, then it has to be the result of demand-supply interactions, and not of menu costs.

Model Variant E is the same as Variant D with the exception that demand-supply interactions are turned on. Before running simulations with Variant E, a numerical value has to be chosen for parameter η that determines the strength of demand-supply interactions.

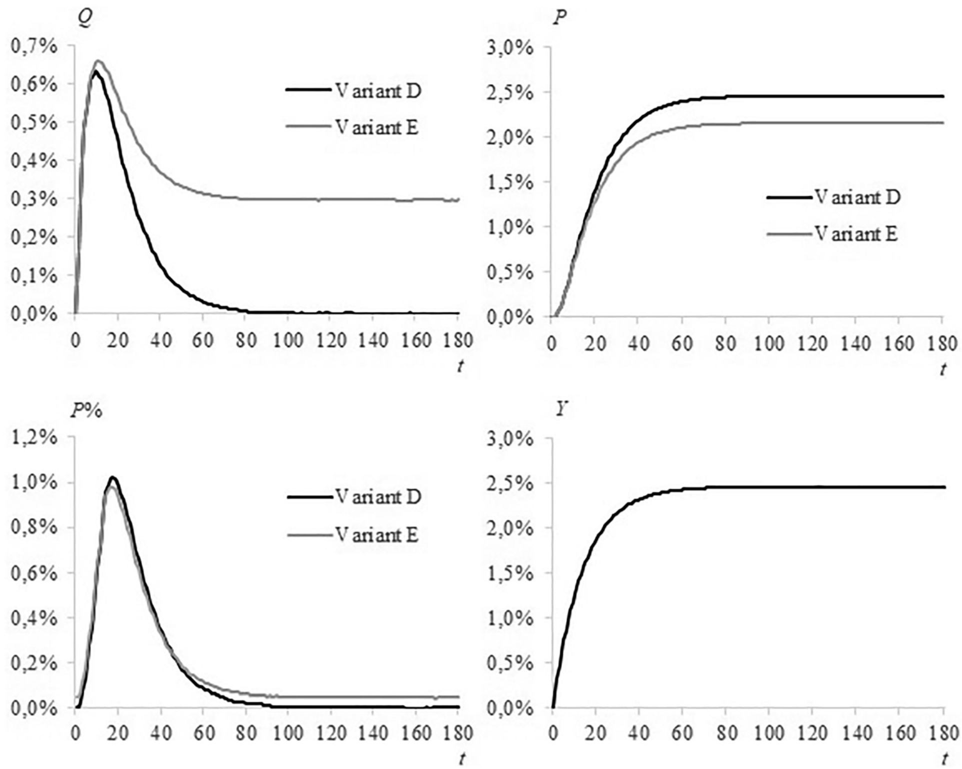

Fig. 4. **The impulse responses of *Q*, *P*, *P*%, and the level of *Y* to a one standard deviation positive transitory shock to the growth rate of *Y* in Model Variants D and E**
***Note*: *Q* = Real aggregate output, *P* = Price level, *P*% = Inflation rate, *Y* = Nominal aggregate demand.**

DeLong and Summers (2012) use equation (4) to come up with several rough estimates for the value of η and they conclude using annual data that it has to be around 0.24. The model presented in this paper is calibrated to monthly frequency, implying that the value of η has to be set roughly to $0.24/12 = 0.02$ to be consistent with the estimate of DeLong – Summers (2012).[34] The set of parameters estimated with the SMM procedure is the same as in the case of Model Variant D, and Table 1 makes it clear that the goodness of fit of Variant E to the empirical moments can be considered as equally good as that of Variant D.

Figure 4 can be used to compare the impulse responses of the two model variants to a typical – one standard deviation – positive monetary shock. The impulse response of Variant E makes it clear that demand-supply interactions reintroduce hysteresis into the model even in the presence of idiosyncratic productivity shocks. The short-run positive real effect of the monetary shock generated by the stickiness of price adjustment and by the bounded rationality of price decisions

[34]The working paper version of this article (Váry 2020) also presents a simple estimate for η on monthly frequency, which is around 0.02, as well.

manifests itself in the form of a positive output gap, which leads to an increasing potential output through the mechanisms of demand-supply interactions. In the long run, the unfolding process of price adjustment increases the price level, thereby reducing real aggregate demand and output. However, firms do not adjust to the same supply potentials as the ones prevalent before the arrival of the monetary shock, but they adjust to permanently higher ones. The result is that real aggregate output settles down at a permanently higher steady-state value compared to the initial one, meaning that a transitory shock to the growth rate of nominal aggregate demand has a permanent effect on the level of real aggregate output, the dynamics of which turns out to be hysteretic.

It is concluded that demand-supply interactions are able to serve as theoretically, as well as empirically plausible explanations for the possible presence of hysteresis in the dynamics of empirical GDP. This also suggests that demand-supply interactions may be more relevant for explaining the empirical evidence against long-run monetary neutrality, than the other economic mechanism emphasized by post-Keynesian economists, which is the nonlinear nature of price adjustment.

6. CONCLUDING REMARKS

We developed an agent-based menu cost model to study whether menu costs lead to hysteresis in aggregate output, or not. The empirical relevance of different variants of the model was assessed by calibrating them to match some important moments of two empirical distributions related to micro-level price adjustment, and by analyzing if they are able to reproduce some key moments of these empirical distributions sufficiently well.

It was found that it was theoretically possible to come up with model variants, in which the presence of menu costs led to hysteresis in aggregate output, regardless of whether firms were assumed to be boundedly or perfectly rational. However, these simple model variants were not able to fit to the empirical data well. The introduction of idiosyncratic productivity shocks into the model eliminated hysteresis generated by menu costs. Idiosyncratic productivity shocks were necessary for the model to reproduce the large mean size of empirical price changes. Thus, the presence of menu costs was a compelling theoretical explanation for the hysteretic dynamics of aggregate output, but its empirical relevance seems to be ambiguous.

However, the presence of demand-supply interactions as an alternative explanation for hysteresis in aggregate output was relevant not just theoretically, but empirically, as well. The introduction of demand-supply interactions into the agent-based menu cost model resurrected hysteresis even in the presence of idiosyncratic productivity shocks.

According to the results of the model, the presence of menu costs does not seem to make it necessary to reconsider the usual suggestions of the New Neoclassical Synthesis for monetary policy, which are based on the principle of long-run monetary neutrality. However, hysteresis emerging as a consequence of demand-supply interactions implies that money is not neutral in the long run, suggesting that central banks should put more emphasis on following real economic targets besides following their primary target of maintaining a low and stable inflation rate. They are suggested to target additional real economic variables (Garga – Singh 2021; Galí 2022), and/or to follow the flexible opportunistic approach of inflation targeting recommended by Fontana – Palacio-Vera (2007).

Of course, the results presented in the paper have their own limitations, which draw attention to possible ways of continuing the research. One of the most important limitations is that monetary policy is assumed to be exogenous in the model, the central bank does not react endogenously either on inflation or on real economic activity. This is a useful simplification in the first step, as it helps analyzing whether monetary shocks *by themselves*, without any policy intervention, have hysteretic effects, or not. It has turned out that they do under demand-supply interactions, which is not the case in DSGE-type menu cost models that also assume exogenous monetary policy.[35] However, transitory shocks to the *level* of demand do not lead to permanent real effects within new consensus macro models with Taylor-type monetary policy rules, even if demand-supply interactions are present, provided that they are linear (Kienzler – Schmid 2014; Bassi 2016). The endogenous monetary policy reaction to such shocks is able to neutralize their real effects in the long run – provided that the zero lower bound of the nominal interest rate is not effective, and that the interest rate channel of monetary transmission is an efficient channel of aggregate demand management. Therefore, an obvious way of continuing the research is to introduce the role of interest rates explicitly into the model, and to assume that the central bank sets the nominal interest rate by endogenously reacting to the state of the economy. The results of Bassi (2016) suggest that transitory shocks to the *growth rate* of nominal aggregate demand, i.e., permanent shocks to its *level* would have hysteretic effects under endogenous monetary policy, as well, but the real effects of transitory shocks to the *level* of nominal aggregate demand would probably be neutralized in the long run by the endogenous interest rate decisions of the central bank, if demand-supply interactions are linear. However, a more complex, nonlinear way of modeling demand-supply interactions can be hypothesized to resurrect hysteresis even in that case. There are no obvious reasons to believe that all these considerations would change the core message of this paper regarding the (in)ability of menu costs to result in hysteresis in an empirically relevant way.

To sum up, it has been shown that in spite of the well-known capability of some types of fixed costs of market adjustment to generate hysteresis, menu costs do not lead to hysteresis in aggregate output in empirically relevant models according to our existing knowledge. The reason why hysteresis still emerges in some menu cost models (Delgado 1991; Dixit 1991) is that as opposed to DSGE-type menu cost models, they do not contain idiosyncratic productivity shocks, hence they are not able to reproduce the large mean size of empirical price changes. If one would like to explain why the dynamics of GDP may be hysteretic in reality, it is easier to do it in an empirically plausible way relying on demand-supply interactions instead of menu costs. If one still insists that menu costs play an important role in generating hysteretic macro-dynamics, one has to find a new assumption, under which the empirical fit of menu cost models remains at least as good as under idiosyncratic productivity shocks, and under which hysteresis caused by the presence of menu costs is not eliminated from the dynamics of aggregate output.

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[35] Cross et al. (2012) do not model endogenous monetary policy reactions in their hysteresis model, either.

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