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IS CAPACITY UTILIZATION VARIABLE IN THE LONG RUN? AN AGENT-BASED SECTORAL APPROACH TO MODELING HYSTERESIS IN THE NORMAL RATE OF CAPACITY UTILIZATION

Federico Bassi, Tom Bauermann, Dany Lang, Mark Setterfield [1]

ABSTRACT

Post Keynesian macrodynamic models make various assumptions about the normal rate of capacity utilization. Those rooted in the Classical and neo-Keynesian traditions assume the normal rate is fixed, whereas Kaleckian models treat it as a variable that is endogenous to the actual rate of capacity utilization. This paper contributes to the debate about the normal rate of capacity utilization by developing a model of strong or genuine hysteresis, in which firms make discrete decisions about the normal rate depending on the degree of uncertainty about demand conditions. An agent-based model based on empirical analysis of 25 sectors of the US economy is used to show that hysteresis can cause variation in the normal rate of capacity utilization within a subset of the range of observed variation in the actual capacity utilization rate. This suggests that the economy exhibits both constancy and (endogenous) variability in the normal rate of utilization over different ranges of variation in the actual rate. More broadly speaking, the genuine hysteresis model is shown to provide the basis for a synthesis of Post Keynesian macrodynamics that draws on both the Classical/neo-Keynesian and Kaleckian modeling traditions.

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Is capacity utilization variable in the long run? An agent-based sectoral approach to modeling hysteresis in the normal rate of capacity utilization

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June 9, 2020

Abstract

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Keywords: Normal rate of capacity utilization, Harrodian instability, genuine hysteresis, Kaleckian growth theory

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1 Introduction

Assumptions about the normal rate of capacity utilization are crucial in Post Keynesian macrodynamic models. The debate revolves around two positions, Kaleckian and Classical/ neo-Keynesian. For Classical/neo-Keynesian economists (Serrano, 1995; Skott, 2010), the normal rate of capacity utilization is fixed and the actual rate adjusts towards the normal rate in the long run. Kaleckian authors such as Lavoie (1996) and Dutt (1997) instead emphasize that the normal rate is a variable that adjusts to the actual rate of capacity utilization. Skott (2012) criticizes the Kaleckian approach on the grounds that it lacks: 1) proper behavioral foundations; 2) an explanation as to why the normal rate of capacity utilization should be treated as a conventional variable; and 3) justification for a process of adaptation in the normal rate that is both quantitatively fast and unbounded.[1] Setterfield and Avritzer (2019) take up these points by suggesting a genuine hysteresis mechanism operating in the normal rate of capacity utilization. They argue that the normal rate depends on fluctuations in the actual rate of capacity utilization because the latter reflects variations in uncertainty about aggregate demand and that, in the absence of rational expectations, the normal rate of capacity utilization must be partly conventional because it reflects behavior under uncertainty. Finally, it is claimed that the genuine hysteresis model provides a basis for countering the third critique of Skott (2012).

The analysis in Setterfield and Avritzer (2019) is, however, lacking in several respects. First, the authors analyze hysteresis on a purely macroeconomic, i.e. aggregate, level. Capitalist economies are diversified, however, made up of different industries (sectors) with potentially different properties and, in particular, different normal rates of capacity utilization.[2] The approach taken in this paper therefore involves analyzing the the normal rate of capacity utilization at the industry level.

[1] Similar criticisms can be found in Nikiforos (2016), despite the author's finding that the normal rate of utilization is, in fact, endogenous to the actual rate at both micro and macro levels.

[2] On the potential importance of heterogenirty at the sectoral level for Kaleckian macroeconomics, see also Fujita (2019).

Second, even within specific sectors, decisions about the normal rate of capacity utilization are made by individual firms. With the exception of Nikiforos (2013, 2016), this has not been considered properly (to date) in the literature on hysteresis in the normal rate. We therefore develop an agent-based model (ABM) that ultimately roots the mechanisms of genuine hysteresis in firm-level decisions. The approach taken is similar to the application of agent-based models in (social) sciences elsewhere (Railsback and Grimm, 2011).

Third, the paper combines micro- and mesoeconomic modeling with macroeconomics by drawing out the implications of genuine hysteresis at the sectoral level for traditional one-sector, aggregate structural Post Keynesian macrodynamic models. These implications include a modified Kaleckian treatment of the normal rate of capacity utilization that serves to combine Classical/neo-Keynesian and Kaleckian adjustment dynamics. In turn, this modified Kaleckian approach suggests that macrodynamics can involve both periods when the actual rate of capacity utilization adjusts towards the normal rate, and periods when this causal relationship runs in reverse.

The remainder of the paper is organized as follows. Section 2 provides a brief overview of the genuine hysteresis approach to modeling variation in the normal rate of capacity utilization. Section 3 empirically analyzes genuine hysteresis at the sectoral level, while section 4 presents an agent-based model of firm-level decisions. Section 5 presents the implications of the statistical and computational analyses in sections 3 and 4 for Post Keynesian macroeconomic models. Finally, section 6 ends with a brief summary of the main results and findings of the paper, and its implications for future research and policy.

2 Theoretical background and motivation

The past four decades have witnessed repeated appeals to the concept of hysteresis in macroeconomics, in a by-now large literature that is often associated with critiques of the concept of a natural rate of unemployment (and the related claim that the Phillips curve is vertical – i.e., that there is no trade-off between inflation and real activity in the long run).[3] A signal feature of hysteresis – and one that explains its attraction in the literature just noted – is that transitory causes (shocks) can have permanent effects. Hence even if one begins with the canonical (neoclassical) concepts of a natural rate of unemployment and vertical long-run Phillips curve as a starting point, if transitory shocks can cause departures from the natural rate of unemployment, and if such departures change the value of the natural rate itself, then the economy will eventually settle at an equilibrium consistent with a new (higher or lower) long-run rate of unemployment. This means that the long run Phillips curve cannot be vertical.[4] It also overturns the Friedmanite policy implications of the original natural rate hypothesis, according to which monetary policy interventions that (for example) lower unemployment in the short run can only have inflationary consequences in the long run, by virtue of the fixity of the natural rate. With hysteresis, such policy interventions (and, indeed, most nominal 'shocks') are revealed to affect the real economy in the long run – and all without initially setting aside the concept of the natural rate of unemployment itself. Instead, the so-called natural rate remains an integral feature of the analysis, although how 'natural' it can be considered if the value varies in response to the actual rate of unemployment is, of course, debatable (Solow, 1986, p.S33).[5]

Unfortunately, however, appeal to hysteresis in economic theory is often done badly,[6] at least according to those familiar with the origins and development of the concept in the physical sciences (Amable et al., 1993, 1994; Cross, 1993b; Bassi and Lang, 2016). For instance, the term 'hysteresis' is often (indeed, usually) used as a synonym for path dependence, when it is,

[3]The genesis of this 'hysteresis in the natural rate of unemployment' literature is often associated with Blanchard and Summers (1986), though see Hargreaves Heap (1980).

[4]In fact, if the short run change in inflation associated with the transitory shock to unemployment is modest, the process described above will produce a long run Phillips curve that is essentially *horizontal* – consistent with empirical work showing that an important part of the Phillips curve is, in fact, flat (Eisner, 1997).

[5]In particular, a hysteretic 'natural' rate of unemployment is not determined exclusively on the supply-side of the economy, but is, instead, influenced by variations in aggregate demand.

[6]As a consequence, the same could be said of the empirical literature in macroeconomics that claims to test for the presence or absence of hysteresis effects.

in fact, a particular form of path dependence with specific properties that are not are not shared with other forms of path dependence – such as lock in and cumulative causation, for example (Setterfield, 2009). Moreover, the formal structure of hysteresis is frequently (mis)represented as arising from the presence of a unit (zero) root in systems of linear difference (or differential) equations (Amable et al., 1993, 1994; Cross, 1993b). This gives rise to two problems. First, the continuity implicit in linear difference (differential) equations overlooks the fact that hysteresis is, in fact, associated with *discontinuities* in the adjustment dynamics of a system. Second, it altogether misrepresents the fundamental nature of hysteresis. In terms of the conventional 'triad' of equilibrium analysis (existence, uniqueness, and stability), unit/zero root systems give rise to a continuum of equilibria and thus undermine the property of *uniqueness*. Hysteresis, however, undermines the classical mechanical *stability* properties of equilibrium. In a hysteretic system, there may be a unique equilibrium at any point in time. Nevertheless, the system need not revert to its initial equilibrium position following some displacement from it, but will instead settle into a new equilibrium position that is (in part) the product of the disequilibrium adjustment it has just experienced (and that would not have existed as an equilibrium position in the absence of this historical traverse). These and other properties of hysteresis are properly captured by the analytical model of 'genuine' hysteresis developed in the physical sciences and introduced to economics by authors such as Amable et al. (1993, 1994) and Cross (1993b). This having been said, however, it is possible to adopt a 'hybrid' or pragmatic position on the modeling of hysteresis, according to which unit or zero root systems are used as a first approximation even as it is recognized that such systems do not give rise to hysteresis proper (Setterfield, 2009).[7]

A proclivity to appeal to the concept of hysteresis has made its way into the debate con-

[7] This 'hybrid' or pragmatic position can be associated with the sort of methodological position in macroeconomic theory associated with authors such as Krugman (2000). As will become clear, it provides a basis for some of the lessons for modeling hysteresis in the normal rate of capacity utilization that can be drawn from the analysis in this paper.

cerning the long run behavior of the rate of capacity utilization in heterodox macrodynamics, particularly among Kaleckian authors (Lavoie, 1995, 1996, 2010; Dutt, 1997, 2009, 2010).[8] The normal rate of capacity utilization is very different from the so-called natural rate of unemployment. While the latter is usually associated with market-clearing outcomes in the labor market consistent with correct expectations, the former is widely considered to be a convention designed to cope with fundamental uncertainty about demand in the goods market.[9] The essential argument in the Kaleckian literature is that whereas Classical and neo-Keynesian authors are inclined to regard the normal rate of capacity utilization as a fixed point towards which the actual rate of capacity utilization must converge, the normal rate should be thought of instead as endogenous to the actual rate. This thinking is potentially consistent with hysteresis: in principle, even a strictly temporary shock that separates the actual from the normal rate of capacity utilization could move the latter towards the former so that, by the time the actual and normal rates equalize (and the economy achieves a 'fully-adjusted' position), the normal rate of capacity utilization, and hence the long run rate of capacity utilization, has changed.[10]

Unfortunately, all this is achieved without modeling variation in the normal rate of capacity utilization in a manner consistent with genuine hysteresis. Instead, Kaleckians postulate two possible closures in macrodynamic models that involve the normal rate of capacity utilization:

$$u_n = \bar{u}_n \tag{1}$$

and:

$$\dot{u}_n = \beta(u - u_n) \tag{2}$$

[8]Earlier intimations of this thinking can be found in Amadeo (1987) and even as far back as Robinson (1956, pp.186-90).

[9]Conceptions of the normal rate of capacity utilization do differ, however. For example, Kurz (1986, 1990) derives the normal rate from cost-minimizing behaviour associated with the optimal choice of technique by firms.

[10]Note the correspondence in the example just described between the outcome of these dynamics – a permanent change in the equilibrium capacity utilization rate resulting from a temporary change in the actual utilization rate – and the signal feature of hysteresis (permanent change as a result of transitory cause) highlighted earlier in this discussion.

Equation (1) can be termed the Classical/neo-Keynesian closure, and treats the normal rate of capacity utilization as exogenously given. In the event of short-term variation in the actual capacity utilization rate, a fully-adjusted position can only be restored by reversion of the actual rate towards its (fixed) normal rate. Equation (2), meanwhile, is the Kaleckian closure. This makes the normal rate of capacity utilization endogenous to the actual rate so that if, for example, the actual rate rises above the normal rate ($u > u_n$), the normal rate increases and a fully-adjusted position is restored at a new, higher, normal rate of capacity utilization. The Kaleckian closure in (2) is thus associated with hysteresis. However, the formal structure of equation (2) means that it can be associated with the unit/zero root approach to modeling hysteresis that was criticized earlier. To see this, first note that it follows from (2) that:

$$\dot{u}_n \approx u_{nt} - u_{nt-1} = \beta(u_t - u_{nt-1}) \tag{3}$$

Now assume that:

$$u_t = u_{nt-1} + \varepsilon_t \quad , \quad \varepsilon \sim (0, \sigma_\varepsilon^2)$$

Substituting this last expression into (3), we get:

$$u_{nt} = u_{nt-1} + \beta\varepsilon_t \tag{4}$$

The expression in equation (4) is a unit root process ($du_{nt}/du_{nt-1} = 1$). Assume that $u_{nt} = u_{nt-1} = u_{n1}$ initially. Now assume that in some period i, $\varepsilon_i = \alpha \neq 0$ while $\varepsilon_t = 0 \quad \forall \quad t > i$. Then by equation (4) we will observe:

$$u_{ni} = u_{ni-1} + \beta\varepsilon_i = u_{n1} + \beta\alpha$$
$$\Rightarrow u_{ni} = u_{n2}$$

and:

$$u_{nt} = u_{n2} \quad \forall \quad t > i$$

The unit root in the difference equation with which we began ensures that the system does not revert to u_{n1} despite the strictly transitory nature of the disturbance to which it was subject, but instead permanently bears the mark of the temporary event $\varepsilon_i \neq 0$.[11]

More recently, Setterfield and Avritzer (2019) have outlined a Kaleckian model in which variation in the normal rate of capacity utilization is associated with genuine hysteresis. In this model, firms are understood to maintain a normal rate of capacity utilization below one to insulate themselves from unforeseen (due to fundamental uncertainty) variations in product demand that, were they to result in foregone opportunities for expansion, would result in loss of market share and hence loss of power over the external (market) environment. But it is a stylized fact that the volatility of the goods market is subject to discrete variations associated with long periods of growth and tranquility and shorter periods of crisis. According to Setterfield and Avritzer (2019), this will induce firms to engage in discrete switching between 'high' and 'low' values of the normal rate of capacity utilization as they perceive the economy to be enmeshed in regimes of either low or high product market volatility.

This theory lends itself to representation in terms of the analytical apparatus of genuine hysteresis. To see this, consider first figure 1. In figure 1, we depict a non-ideal relay illustrating the workings of genuine hysteresis in the normal rate of capacity utilization at firm-level. The

[11] Difference equations with non-zero roots will, in the event of transitory shock, revert towards or diverge further away from any fixed point at which they begin. Consider, for example, the system:

$$x_t = \delta + \gamma x_{t-1} + \varepsilon_t \quad , \quad \gamma < 0$$

where, once again, $\varepsilon \sim (0, \sigma_\varepsilon^2)$ and with $x = x_0$ and $\varepsilon_0 \neq 0$ (and $\varepsilon_t = 0 \quad \forall \quad t > 0$) in some initial period zero. It follows that:

$$x_t = (1 + \gamma + \ldots + \gamma^t)\delta + \gamma^{t-1}(\gamma x_0 + \varepsilon_0)$$

$$\Rightarrow \lim_{t \to \infty} x_t = \frac{\delta}{(1-\gamma)}$$

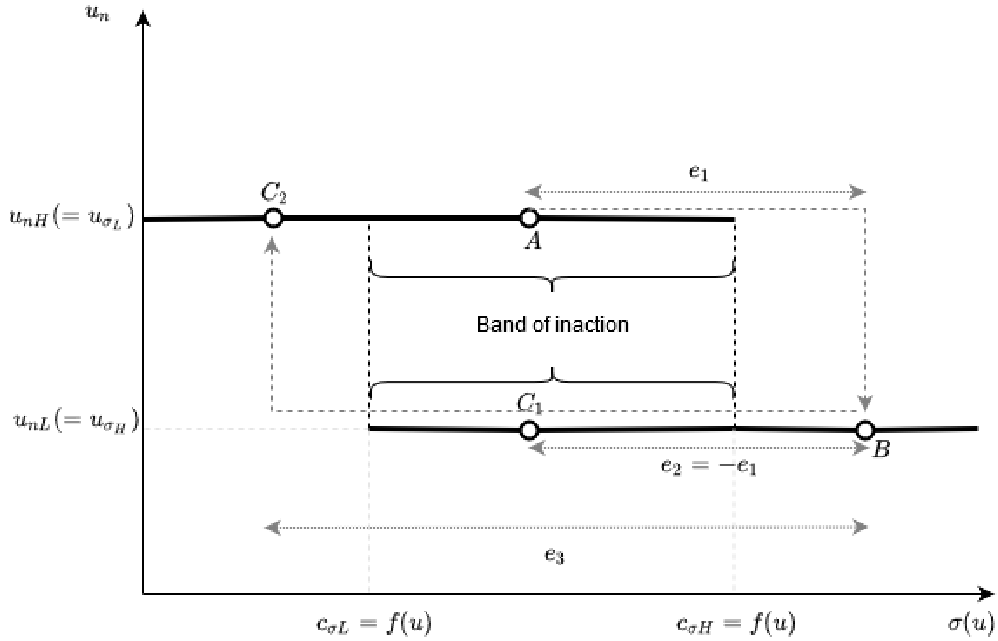
This is a standard 'reversion towards a fixed point' result characteristic of most equilibrium models in economics.

upper and lower 'arms' of the non-ideal relay correspond to u_{nH} and u_{nL}, the upper and lower values of the normal rate of capacity utilization. $c_{\sigma L}$ and $c_{\sigma H}$, meanwhile, are the critical values of σ_u, the volatility of the aggregate economy or market environment in which the firm operates, that induce switching between u_{nH} and u_{nL} as the firm seeks to operate at a normal rate of capacity utilization that insulates it sufficiently from unforeseen future variations in product demand.[12] Starting with the firm operating with $u_n = u_{nH}$ at point A, a sustained increase in the volatility of the actual rate of capacity utilization of size e_1 induces the firm to reduce its normal rate of capacity utilization from u_{nH} to u_{nL} as a hedge against large unforeseen increases in future product demand. The firm thus settles at point B in figure 1. However, if there is now a reduction in volatility of identical magnitude to the previous increase ($e_2 = e_1$), thus restoring the level of volatility to the *status quo ante*, the firm wil *not* revert to u_{nH} because volatility has not fallen below the critical value $c_{\sigma L}$ (the threshold value that signals a 'significant' reduction in σ_u meritorious of behavioral change, bearing in mind the essential motivation for maintaining $u_n < 1$). Instead, the firm settles at point C_1. Only if the reduction in volatility is sufficiently large enough to reduce σ_u below $c_{\sigma L}$ – such as the reduction of size e_3 depicted in figure 1 – will the firm increase u_n from u_{nL} to u_{nH} (bringing it to point C_2). In this way, discrete variations in u_n occur in response to sufficiently large variations in the volatility of the firm's environment, and as demonstrated by the the movement from A to B to C_1 in figure 1, even transitory variations in volatility can have lasting (indeed, *ceteris paribus*, permanent) effects on u_n.

Unfortunately, the model developed in Setterfield and Avritzer (2019) is a single-sector, aggregate structural model, so figure 1 is conceived as depicting the behavior of a single, representative firm. In this case, the aggregate normal rate of capacity utilization will vary discretely between the two extreme values u_{nL} to u_{nH} in figure 1. Genuine hysteresis in aggregate outcomes is, however, properly conceived as arising from microfoundations that rest on heterogeneous parts. In other words, genuine hysteresis in the aggregate normal rate of capacity utilization

[12]See Setterfield and Avritzer (2019) for further discussion of this behavior.

Figure 1: Modeling genuine hysteresis in capacity utilization



would arise from aggregation of the behavioural responses of multiple firms, with differing values of u_{nL}, u_{nH} and/or c_{σ_L} and c_{σ_H}, responding (in accordance with the principles illustrated in figure 1 and outlined above) to variations in the volatility of the economy. Ultimately, such variation can be (more or less) continuous even as variation in the normal rate at firm-level is discrete, due to heterogeneity in the micro-structure of the economy. In this way, genuine hysteresis in the normal rate of capacity utilization can be associated with compositional change (change in the proportion of firms operating at either u_{nL} to u_{nH}) in an economy characterized by heterogeneity among firms. The immediate purpose of what follows is to demonstrate these claims more concretely, by constructing a microfounded genuine hysteretic model of variation in the normal rate of capacity utilization at the sectoral level.

3 Empirical analysis of volatility and the normal rate of capacity utilization

3.1 Empirical analysis of hysteresis effects

Based on (Steindl, 1952), uncertainty about demand conditions is a basic motivation for firms to plan to operate with excess capacity (i.e., to set $u_n < 1$). It follows that an increase in uncertainty can induce a lower value of u_n to accommodate bigger potential future variations in demand and, hence, realized capacity utilization rates. Therefore, and assuming backward-looking behavior on the part of firms, larger fluctuations in the actual rate of capacity utilization in the past indicate times of rising uncertainty for firms. Setterfield and Avritzer (2019) show that there is a negative relation between the volatility in the actual rate of capacity utilization and the normal rate of capacity utilization in the aggregate. Nevertheless, the authors do not address whether or not such a relationship exists at the micro- and mesoeconomic levels.

The empirical analysis in this paper has two objectives. First, it tests whether the inverse relationship between uncertainty and the normal capacity utilization rate reported by Setterfield and Avritzer (2019) exists at the mesoeconomic level, i.e., for 25 manufacturing sectors of the US economy.[13] Second, and with reference to figure 1, we seek evidence for the basic properties of genuine hysteresis in the normal rate of capacity utilization at the sectoral level. The sectors are the same as in Setterfield (2019) and the data was taken from the Federal Reserve Data (FRED) on the capacity utilization rate.[14] We take monthly data on the actual capacity utilization rate

[13]The non-constancy of the volatility of the economy, and the inverse relationship between volatility and the actual rate of capacity utilization as between long booms (sustained periods of high capacity utilization) and short crises (characterized by low capacity utilization) are assumed to be characteristics of the mesoeconomic level as they are, in Setterfield and Avritzer (2019), of the economy as a whole.

[14]These sectors are: Apparel and leather goods; Chemical; Computers and electronic product; Computers, communications equipment, and semiconductors; Crude processing; Electrical equipment, appliance, and component; Electric power generation, transmission, and distribution; Fabricated metal product; Food, beverage, and tobacco; Furniture and related products; Machinery; Mining; Miscellaneous; Motor vehicles and parts; Natural gas distribution; Non-metallic mineral mining and quarrying; Oil and gas extraction; Paper; Petroleum and coal products; Plastics and rubber products; Primary metal; Printing and related support activities; Textiles and prod-

from 1972 to 2018 and split the data into 47 years. For each year, we compute the average actual capacity utilization rate and its standard deviation. Taking into consideration the critique of Botte (2019), we then compute the normal rate of capacity utilization (u_n) as the five-year moving average (5-MA) of the average capacity utilization rates calculated for each calendar year and removed the linear trend. [15] We also compute a five-year moving average (5-MA) of the standard deviation calculated for each calendar year. The (filtered) standard deviation indicates the volatility of the actual rate of capacity utilization (σ_t), and provides a measure of the uncertainty faced by firms (as in Setterfield and Avritzer (2019) and Jurado et al. (2015)).

In their paper on the effect of real sales on hysteretic employment, Mota et al. (2012) present three criteria that indicate hysteresis. We refer to Mota et al. (2012) for our first econometric tests. The data can be said to confirm the predictions of the non-ideal relay (figure 1) in our model if the following conditions are met:

i) As depicted in figure 1, when σ_{t-1} increases we should see that the normal rate of capacity utilization decreases. In other words, we should see a negative correlation between changes in σ_{t-1} and changes in u_n.

ii) Further shown by the non-ideal relay (figure 1), firms do not constantly adjust u_n as σ changes, but instead change u_n only when σ exceeds or falls below certain critical values. Therefore, given changes in σ, one should see that the frequency of non-adjustment in u_n should dominate positive and negative changes in σ over the sample period from 1972 to 2018.

iii) Finally, and in line with (ii), we should see an asymmetry in the impulses from σ_{t-1} and the responses from u_n – specifically, we should see that the variation of σ_{t-1} exceeds the variation of u_n.

Table 1 shows the results with respect to the above-mentioned criteria. The last column of the table 1 and figures 11 to 13 in the Appendix show that the correlation between $\Delta\sigma$ and Δu_n

ucts; Transportation equipment; Wood product

[15] We varied the lags for the MA-filter from 3 to 7. The results remained nearly unaffected.

is negative for nearly all sectors. Criterion (i) is mainly confirmed, although the observed correlation is very low in the sectors *Electric Power Generation, Transmission and Distribution, Food, beverage and tobacco, Natural gas distribution* and *Oil and gas extraction.* Columns 2 to 5 of table 1 show the magnitude of the adjustments in u_n, given changes in σ_{t-1}. As is can be seen in the mentioned columns, for the majority of the sectors u_n does not significantly change when σ_{t-1} changes. These columns therefore confirm the prediction of the non-ideal relay (criterion (ii)). The frequency of non-adjustment dominates the positive and negative spikes for the period from 1972 to 2018 in most of the sectors. Further, columns 4 and 5 show the variation in the rates of changes in σ_{t-1} exceed the variation in Δu_n, which indicates that firms are reluctant to change u_n in response to any and every change in σ_{t-1}. Hence, criterion (iii) is also confirmed.

Table 1: Frequency of (non-)adjustment to changes in the volatility of actual capacity utilization

Sector	**frequency of positive spikes**	**frequency of negative spikes**	**frequency of non-adjust.**	**Variation in Δu_n**	**Variation in $\Delta\sigma$**	**Cor. Δu_n and $\Delta\sigma_{t-1}$**
Apparel and leather goods	0.07	0.26	0.67	0.014	0.212	-0.491
Chemical	0.13	0.20	0.67	0.015	0.221	-0.355
Computer and electronic product	0.13	0.26	0.61	0.021	0.225	-0.338
Computers, communications equipment and semiconductors	0.17	0.28	0.54	0.027	0.245	-0.328
Crude processing	0.04	0.13	0.83	0.011	0.232	-0.313
Electric Power Generation, Transmission and Distribution	0.07	0.20	0.74	0.011	0.232	-0.168
Electrical equipment appliance and component	0.20	0.33	0.48	0.012	0.133	-0.587
Fabricated metal product	0.22	0.28	0.50	0.021	0.254	-0.492
Food, beverage and tobacco	0.00	0.07	0.93	0.007	0.161	-0.121
Furniture and related products	0.22	0.33	0.46	0.027	0.182	-0.365
Machinery	0.28	0.33	0.39	0.028	0.181	-0.519
Mining	0.07	0.11	0.83	0.011	0.222	-0.213
Miscellaneous	0.37	0.24	0.39	0.012	0.128	-0.363
Motor vehicles and parts	0.30	0.33	0.37	0.044	0.182	-0.575
Natural gas distribution	0.07	0.17	0.76	0.013	0.085	-0.004
Non-metallic mineral mining and quarrying	0.17	0.15	0.67	0.022	0.127	-0.385
Oil and gas extraction	0.00	0.00	1.00	0.007	0.219	-0.143
Paper	0.07	0.02	0.91	0.010	0.202	-0.679
Petroleum and coal products	0.11	0.22	0.67	0.017	0.145	-0.39
Plastics and rubber products	0.28	0.33	0.39	0.025	0.178	-0.425
Primary metal	0.22	0.35	0.43	0.032	0.157	-0.392
Printing and Related Support Activities	0.13	0.26	0.61	0.018	0.174	-0.336
Textiles and Products	0.11	0.28	0.61	0.021	0.255	-0.564
Transportation equipment	0.22	0.24	0.54	0.024	0.210	-0.489
Wood product	0.24	0.33	0.43	0.032	0.222	-0.574
Total Industy	0.09	0.17	0.74	0.013	0.262	-0.61

Source: Federal Reserve Bank of St. Louis (FRED) and the US, and own calculation.
Description: The first column shows the industries, following the classification of the US industries by FRED (Setterfield, 2019). The column 2 to 4 show the frequency of various magnitudes of period-to-period-changes in u_n, i.e. frequency of positive spikes ($\frac{\Delta u_n}{u_n} > 1.5\%$), frequency of negative spikes ($\frac{\Delta u_n}{u_n} < -1.5\%$) and inaction ($\frac{\Delta u_n}{u_n} < |1.5\%|$). They are expressed as the share of all changes. Columns 5 and 6 show the standard deviation of the period-to-period-changes in u_n and σ_{t-1}.

3.2 Estimation of the sectoral threshold values of u_n and c_σ

This section presents further evidence for the genuine hysteresis model (figure 1), seeking in the process to approximate u_{nH} and u_{nL} and establish threshold values for σ_{t-1} on the sectoral level. A common approach to empirically analyzing the hysteresis mechanism depicted in figure 1 involves estimating a discrete threshold regression model (Hansen, 1999) for all 25 sectors (e.g. Belke et al. (2015)). The discrete threshold regression model, which we apply to approximate the sector-specific values of u_{nL} and u_{nH}, estimates two linear regressions with two different intercepts plus an error term. The regressions are separated by the threshold value of σ_{t-1}. In other words, we estimate the sector-specific values of u_{nH} and u_{nL} as two constants with error terms, as follows:

$$u_{nt} = C_1 + \epsilon_t \quad \text{if} \quad 0 < \sigma_{t-1} < \sigma_{thresh} \tag{5}$$

$$u_{nt} = C_2 + \epsilon_t \quad \text{if} \quad \sigma_{thresh} < \sigma_{t-1} < \infty \tag{6}$$

In equations (18) and (19), the normal capacity utilization rate is the dependent variable and σ_{t-1} is the threshold variable, with $C_2 < C_1$ if our postulated inverse relationship between volatility and the normal rate of capacity utilization is valid. As previously noted, the sectoral normal rate of capacity utilization (u_n) is the detrended five-year moving average (5-MA) of the average capacity utilization rate for each calendar year, while the volatility variable σ_{t-1} is the five-year moving average (5-MA) of the standard deviation of the actual rate of capacity utilization within each calendar year. In table 2, we see that in most sectors, whenever the volatility switches from below to above a certain threshold value (and vice versa), the normal rate of capacity utilization switches from a high utilization regime, u_{nH}, to a low utilization regime, u_{nL} (and vice versa). The second and third columns of table 2 report the estimated intercept values according to the volatility regime (u_{nL} and u_{nH} respectively), while the fourth column reports the estimated threshold value of volatility. In addition, figures 14 to 16 in the Appendix show the negative and non-linear relationship between volatility and the normal rate of capacity utilization derived from our threshold regression model. This is an additional confirmation of the hysteresis mechanism at the mesoeconomic level and the previous works of Setterfield (2019) and Setterfield and Avritzer (2019). Table 10 in the Appendix provides a robustness check for our results.

Table 2: Results: discrete threshold regression model

Sector	C_1	C_2	**Threshold** σ_{t-1}	R^2
Apparel and leather goods	80.84***	75.72***	1.23	0.376
Chemical	78.54***	75.05***	1.24	0.396
Computer and electronic product	79.18***	73.08***	2.01	0.696
Computers, communications equipment, and semiconductors	78.61***	72.85***	2.57	0.313
Crude processing	86.90***	84.74***	1.65	0.309
Electrical equipment, appliance, and component	84.69***	80.85***	1.45	0.230
Electric power generation, transmission and distribution	87.01***	-	-	-
Fabricated metal product	78.33***	73.58***	2.16	0.149
Food, beverage and tobacco	80.76***	-	-	-
Furniture and related products	78.88***	75.36***	1.59	0.157
Machinery	79.17***	72.20***	2.66	0.286
Mining	88.37***	85.90***	1.53	0.230
Miscellaneous	77.58***	75.25***	1.12	0.374
Motor vehicles and parts	78.62***	69.15***	4.31	0.477
Natural gas distribution	80.47***	-	-	-
Non-metallic mineral product	84.73***	77.51***	3.13	0.692
Oil and gas extraction	92.81***	-	-	-
Paper	88.10***	86.08***	1.23	0.292
Petroleum and coal products	87.15***	80.91***	1.87	0.319
Plastics and rubber products	85.18***	79.33***	1.36	0.422
Primary metal	81.26***	74.55***	3.52	0.237
Printing and related support activities	81.57***	77.20***	1.30	0.258
Textiles and products	81.16***	76.27***	1.82	0.261
Transportation equipment	75.99***	68.41***	3.30	0.569
Wood product	80.16***	71.55***	2.18	0.692

Source: Federal Reserve Bank of St. Louis (FRED) and the US, and own calculations.
Notes: *** denotes significance at the 0.1% level.
Description: The Table shows the results for a threshold regression model, estimated via OLS. The data was trimmed by 15% for the regression. The normal rate of capacity utilization (u_n) is the dependent variable. The threshold is tested via the Bai-Perron test (Bai and Perron, 2003). The model tests whether a threshold value of σ_{t-1} exists such that the OLS regression yields two constants (C_1 and C_2) for u_n. For most of the sectors, intercept C_1 is above intercept C_2, which implies that the normal rate of capacity utilization is higher in case of σ_{t-1}-values below the threshold. For the sectors *Electric power generation, transmission and distribution*;*Food, beverage and tobacco*; *Natural gas distribution* and *Oil and gas extraction* we cannot find a threshold value. For the sector *Fabricated Metal*, we can only find significant results if the level of significance is extended to 10% and trimming to 10%. The model was estimated with EViews 11.

4 Modeling hysteresis in the normal rate of capacity utilization

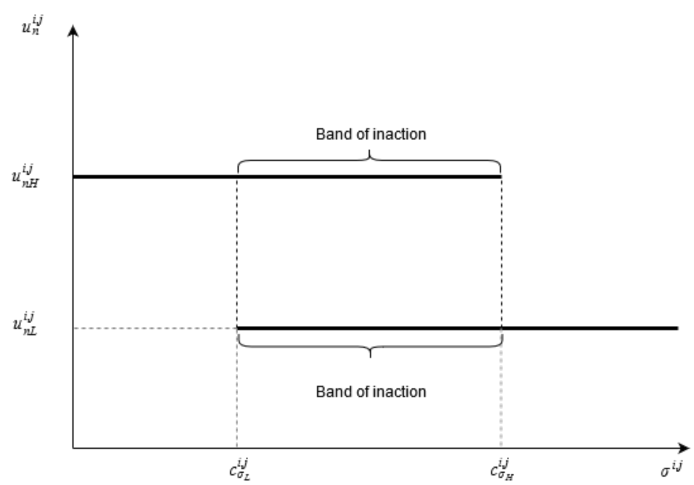
4.1 An ABM of hysteresis in the normal rate of capacity utilization

Capacity utilization, normal as well as actual, is ultimately determined at firm-level. In line with the Steindlian perspective (Steindl, 1952; Lavoie et al., 2004), we treat the normal rate of capacity utilization as a firm-specific convention, while the actual rate of capacity utilization is regarded as an object of exogenous fluctuations (Lavoie, 1996). Based on these premises, in this section we build a simple agent-based model that starts from the individual level. Our objectives are threefold. First, we want to show how firm-level decisions about capacity utilization transmit to the sectoral rate of capacity utilization. Second, by using a calibrated ABM, we want to see whether or not hysteretic dynamics at firm-level give rise to realistic results at the more aggregated (sectoral and macroeconomic) level. Finally, we want to examine the implications of our analysis for the relationship between u_n and u.

The model consists of 20,000 firms distributed across 25 manufacturing sectors according to the relative importance weights, RIW, of these sectors in the US economy (see table 9 and descriptions for further details). The sectors we consider are the same as those to which we appealed in the previous section. The RIW were taken from Setterfield (2019). As described, firms adjust their normal rate of capacity utilization depending on the volatility of the actual capacity utilization rate, as in figure 1. For the sake of simplicity, only firms are considered in our model. The rest of the economy (households, the financial sector, the primary and tertiary sectors, and the foreign and public sectors) are not explicitly modeled. Demand for output and the actual rate of capacity utilization are treated as exogenous.

At the beginning of each period, each firm i ($i = 1;\ldots;20,000$) in each sector j ($j = 1;\ldots;25$) receives an exogenous and sector-specific volatility shock, $\sigma_t^{i,j}$. A period in the model is regarded as corresponding to one calendar year. $\sigma_t^{i,j}$ is a random draw from a sector-specific log-normal distribution. The distributions are fitted to the empirical data available on each of the above-mentioned sectors of the US economy, taken from the period 1972 to 2018. The data further reveals that these sectors do not act independently of each other. Fluctuations in the demand for the goods of one sector cause fluctuations in the demand for goods in other sectors. Therefore, the log-normal distributions, from which the values of $\sigma_t^{i,j}$ are drawn, reflect not only the sector-specific log-normal distribution of volatility in actual capacity (exogenous demand) but also the correlation structure between sectors for the period 1972 to 2018. In other words, $\sigma_t^{i,j}$ is a random, sector-specific variable drawn from a multivariate log-normal distribution. Tables 5 to 9 in the Appendix show the necessary parameters for the log-normal distributions and the correlation matrix. In what follows, we assume that $\sigma_t^{i,j} = \sigma_t^j$ for all firms in a specific sector j.

Figure 2: Model of genuine hysteresis in capacity utilization for each firm i in sector j



Once they receive the volatility shock $\sigma_t^{i,j}$, firms decide on u_n ($u_n = \{u_{nL}^{i,j}; u_{nH}^{i,j}\}$) based on consideration of $c_{\sigma H}^{i,j}$ and $c_{\sigma L}^{i,j}$, the upper and lower critical values of $\sigma^{i,j}$, as in figure 2. The firm-specific variables, $u_{nL}^{i,j}$, $u_{nH}^{i,j}$, $c_{\sigma H}^{i,j}$ and $c_{\sigma L}^{i,j}$, follow the sector-specific levels. We assume that all firms in a sector have the same u_{nH} and u_{nL}, as specified in equations (7) and (8) below. These are the maximum and minimum of the (sectoral) normal rate of capacity utilization in each sector. The rational behind this is that the sectoral maximum (minimum) of u_n is attained when all firms adjusted their normal rate of capacity utilization towards $u_{nH}^{i,j}$ ($u_{nL}^{i,j}$):

$$u_{nL}^{i,j} = u_{nL}^{j} \tag{7}$$

$$u_{nH}^{i,j} = u_{nH}^{j} \tag{8}$$

The critical values of σ are described as follows:

$$c_{\sigma H}^{i,j} = c_{\sigma}^{j} + \gamma_U^{i,j} \quad \text{with} \quad \gamma_U^{i,j} \sim U(0,(H^j - c_{\sigma}^{j})) \quad \text{and} \quad H^j = c_{\sigma}^{j} + \chi^{Uj} \tag{9}$$

$$c_{\sigma L}^{i,j} = L^j + \gamma_L^{i,j} \quad \text{with} \quad \gamma_L^{i,j} \sim U(0,(c_{\sigma}^{j} - L^j)) \quad \text{and} \quad L^j = \max[0.1; c_{\sigma}^{j} - \chi^{Lj}] \tag{10}$$

In equation (9), each firm sets its upper critical value ($c_{\sigma H}^{i,j}$) to the sector-specific threshold value of c_{σ}^{j}, taken from table 2, plus a random firm-specific mark-up, which is assumed to be uniformly distributed. A similar procedure is used to find the lower critical value, $c_{\sigma L}^{i,j}$ (equation (10)). Since adjustment of utilization is expensive (and its purpose uncertain), firms are likely reluctant to adjust $u_n^{i,j}$ if there is just a single period for which $\sigma_{t-1}^{i,j}$ lies above or below the critical values. Instead, firms are treated as adjusting u_n if the average value of $\sigma^{i,j}$ in the most recent m (respectively z) periods lies above (below) the critical values:

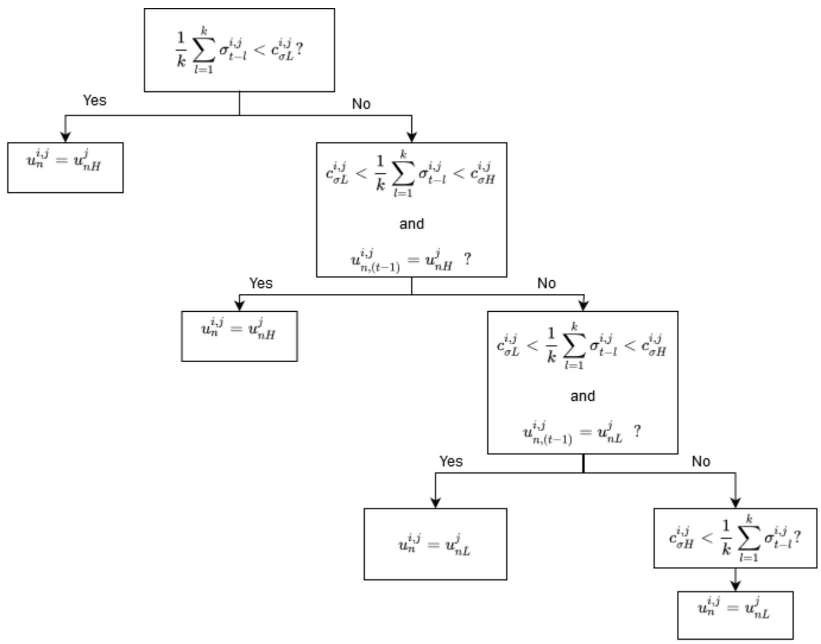
$$\frac{1}{m}\sum_{l=1}^{m} \sigma_{t-l}^{i,j} > c_{\sigma H}^{i,j} \tag{11}$$

$$\frac{1}{z}\sum_{l=1}^{z} \sigma_{t-l}^{i,j} < c_{\sigma L}^{i,j} \tag{12}$$

where the parameters m and z (respectively) represent the average number of periods required for a firm in any given sector to decide that observed volatility exceeds (falls below) the threshold value necessary to induce a change in the normal rate of capacity utilization to u_{nL} (u_{nH}) in figure 2. The number of periods m and z considered by firms is sector- and regime-specific, but in general satisfies $m < z$. This is because firms are understood to adjust u_n quickly to u_{nL} when they see signs of higher volatility (increased uncertainty) consistent with the onset of a crisis. However, firms only slowly adjust to states of tranquility, i.e., the low volatlity (reduced uncertainty) environment characteristic of long booms. This behavior accounts for the fact that, as in equations (11) and (12), firms respond more quickly to the onset of crises as confidence is fractured, whereas pessimistic perceptions are persistent (consistent with the process of 'forgetting the last crisis' taking longer than the reaction to its onset), so that the recovery of 'boom time' thinking and behavior is delayed as confidence is only gradually restored (Irons, 2009).

In summary, in each period, each firm receives an exogenous voatility shock $\sigma^{i,j}$ and, depending on whether the average of recent values of σ exceeds (falls below) the critical value $c_{\sigma H}$ ($c_{\sigma L}$), adjusts u_n accordingly. Figure 3 illustrates the decision-making process of each firm with respect to $u_n^{i,j}$. The calibration of the model is described in detail in section 7.4 of the Appendix.

Figure 3: Choice of u_n: the i^{th} firm's decision tree



Description: u_n, $u_{nL}, u_{nH}, c_{\sigma_L} c_{\sigma_H}$ are as described above. $u_n(t-1)$ describes $u_n^{i,j}$ in the previous period. σ denotes the current (exogenous) volatility. Each firm computes the average σ over k preceding periods (m or z, depending on state of economy). The firm decides on its normal rate of capacity utilization, following the decision tree (figure 3), starting in the upper left part of the figure.

4.2 Comparing empirical to artificial data

Table 3 shows the performance of the model when compared to the empirical data. It shows the results of the discrete threshold regression model and the average values of u_n for the empirical sectoral data (as previously reported in table 2) compared to the calibrated model, as described in section 4.1. The model was (simultaneously) simulated for 20,000 firms spread over 25 sectors, with their specific values for $u_{nL}^{i,j}$, $u_{nH}^{i,j}$, $c_{\sigma L}^{i,j}$ and $c_{\sigma H}^{i,j}$, for 400 consecutive periods. The values for the threshold regressions using the model output were computed over the periods 50 to 400, to account for 'burn-in' periods.[16] The sector-specific values for σ_t^j are random realizations from multivariate log-normal distributions, as described above and in more detail in section 7.4 in the Appendix. The artificial data depicts the average values calculated over 100 runs, i.e. 100 different random seeds.

Given its coarse-grained calibration,[17] the model has significant explanatory power for observed patterns on the industry-level, since we are able to reproduce the aggregate patterns in the empirical data. We observe two normal rate of capacity utilization regimes separated by a single break point in σ^j, starting from a model in which firms behave according to the non-ideal relay based on two break points (as in figure 2). In most cases the model also does a good job of capturing the actual values of variables derived from the discrete threshold regression model estimated using the empirical data (see, for example, the *Electrical equipment, appliance, and component*, *Crude processing* or *Machinery* sectors). Finally, the average values of the sectoral normal rate of capacity utilization are close to the empirical values.

[16]Similar to Monte-Carlo simulations, ABM in practice considers burn-in periods. The system needs a certain number of periods to adjust to its normal or average behavior, for example the average normal rate of capacity utilization.

[17]The reader is again referred to section 7.4 in the Appendix.

Table 3: Results of the discrete threshold regression model (empirical vs. artificial time series) and average u_n

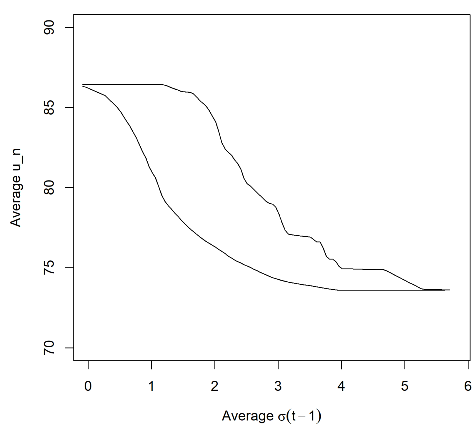
	Empirical Data				Artificial Data			
Sector	C_1	C_2	**Threshold** (σ_{t-1})	**Average** u_n	C_1	C_2	**Threshold** (σ_{t-1})	**Average** u_n
Apparel and leather goods	80.84	75.72	1.23	76.78	79.67	76.49	1.65	78.37
Chemical	78.54	75.05	1.24	77.00	78.41	75.05	1.54	77.54
Computer and electronic product	79.18	73.08	2.01	77.81	79.30	75.98	2.06	78.67
Computers, communications equipment, and semiconductors	78.61	72.85	2.57	77.56	81.06	75.12	2.79	79.88
Crude processing	86.90	84.74	1.65	86.30	86.70	84.68	1.88	86.29
Electrical equipment, appliance, and component	84.69	80.85	1.45	82.51	84.40	80.99	1.56	85.97
Electric power generation, transmission and distribution	-	-	1.74	87.13	89.83	85.14	1.78	88.32
Fabricated metal product	78.33	73.58	2.16	77.94	77.91	76.25	1.67	78.44
Food, beverage and tobacco	-	-	0.81	80.77	80.68	79.87	0.87	80.45
Furniture and related products	78.88	75.36	1.59	77.56	78.16	73.06	2.04	77.20
Machinery	79.17	72.20	2.66	78.11	79.65	74.99	2.58	78.55
Mining	88.37	85.90	1.53	87.34	87.98	85.80	1.92	87.44
Miscellaneous	77.58	75.25	1.12	76.59	77.53	75.19	1.46	77.00
Motor vehicles and parts	78.62	69.15	4.31	75.41	78.38	69.06	4.73	76.49
Natural gas distribution	-	-	3.64	80.68	83.39	80.23	4.01	79.74
Non-metallic mineral product	84.73	77.51	3.13	83.12	84.19	80.53	3.15	83.51
Oil and gas extraction	-	-	1.08	92.89	93.39	92.79	1.27	92.86
Paper	88.10	86.08	1.23	86.91	88.13	86.30	1.45	87.36
Petroleum and coal products	87.15	80.91	1.87	85.54	87.44	83.13	1.99	86.37
Plastics and rubber products	85.18	79.33	1.36	82.29	83.25	77.19	1.85	85.35
Primary metal	81.26	74.55	3.52	78.77	82.77	75.09	3.74	81.07
Printing andrRelated support activities	81.57	77.20	1.30	80.43	82.45	78.97	1.37	80.96
Textiles and products	81.16	76.27	1.82	79.45	80.65	76.41	2.20	79.53
Transportation equipment	75.99	68.41	3.30	74.82	76.21	74.54	2.45	75.65
Wood product	80.16	71.55	2.18	77.14	78.90	71.38	2.77	77.20

Source: Own calculations and simulations. The values for the empirical Data was taken from table 2. The threshold values for the four sectors without a threshold in σ_{t-1} were approximated with the mean. The artificial data was simulated via Netlog and computed via R-Studio. The values are the average values of 100 runs.

4.3 Baseline simulations

Based on the formal description and the calibration, and setting aside the correlation between the volatility of different sectors (i.e. no draw from multivariate log-normal distributions), we can use the model developed so far to simulate a hysteresis loop or 'Ewing loop' (Cross, 1993a) for the aggregate economy, i.e. the macroeconomy. For this purpose, the model is simulated for 20,000 firms (distributed across 25 sectors) for 250 periods and 200 runs. The simulation starts the uniform $\sigma_0^{i,j} = 0$, which increases by 0.05 until all firms switched from u_{nH} to u_{nL}. Then, the values for $\sigma^{i,j}$ increases until all firms switched back. Figure 4 shows the Ewing loop so derived, depicting the (average) normal capacity utilization rate associated with the (average) standard deviation of the actual capacity utilization rate as the latter first rises and then declines. The model replicates the proto-typical form of the Ewing loop (Cross, 1993a; Adamonis and Göcke, 2019). The upper saturation point is 86.4% and the lower saturation point is 73.6%. These values represent the upper and lower bounds of u_n in the simulated aggregate economy, if the correlation structure among the firms is ignored, and are similar to the results (based on FRED data) reported by Setterfield (2019) for the US economy. Hence the model appears to produce plausible results for the US economy, to which it has been benchmarked.

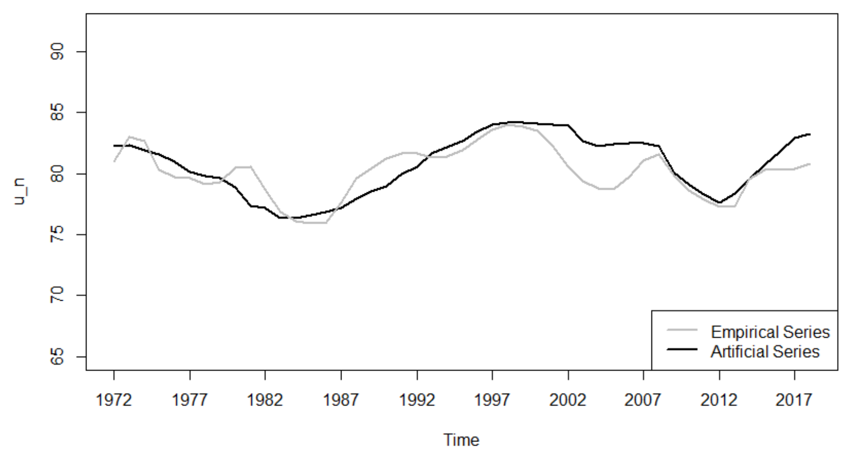
Figure 4: Ewing-Loop in normal capacity utilization on the macroeconomic level



Description: The figure depicts average u_n on the macroeconomic level across changing σ, i.e. the Ewing-Loop. It depicts the average of 200 runs, i.e. random seeds. For the simulation, all 20,000 firms start with σ_t=0.01 at t=0. σ increases uniformly by 0.05, until all firms have switched to $u_{nL}^{i,j}$. Afterwards, σ decreases by 0.05 until all firms switch back to $u_{nH}^{i,j}$. The upper line shows the first periods of increasing volatility and the lower line the periods of decreasing volatility. Cross-correlations of σ are ignored.

Figure 5 depicts the macroeconomic time series of u_n produced by our model (black line), together with the filtered (5MA), detrended empirical time series of u_n (grey line). The artificial time series is the result of inserting the empirical σ of each sector (σ_t^j) into the model for 47 consecutive periods (covering the years 1972 to 2018). The artificial time series is the average over 100 runs. Interestingly, the artificial time series is close to the empirical one. Table 4 reports descriptive statistics for the artificial and the empirical time series. The artificial values are quite close to the empirical ones. Taken together, figure 5 and table 4 show that the output of our model is a reasonable facsimile of the times series it purports to represent.

Figure 5: Time series of the normal capacity utilization on the macroeconomic level



Description: The figure depicts the artificial time series of u_n on the macroeconomic level, i.e. simulated model, and the empirical time series between 1972 and 2018 (without linear trend and applying 5-MA-filter). The grey line shows the artificial time series and the black line the empirical time series. The artificial time series was produced by using the empirical σ on the sectoral level for 20,000 firms. The artificial series depicts the average over 100 runs, i.e., 100 different random seeds, which affect the thresholds for each firm ($c^{i,j}_{\sigma H}$,$c^{i,j}_{\sigma L}$) but not the series of shocks (the sectoral values of σ are the same across runs).

Table 4: Stylized facts of the macroeconomic normal capacity utilization (artificial vs. empirical time series)

	Empirical Time Series	Artificial Time Series
Mean u_n	80.16	80.67
Standard Deviation of u_n	2.06	2.43
Max u_n	84.02	84.21
Min u_n	75.90	76.34

Description: The table shows the mean, the standard deviation, the maximum and the minimum of u_n of the empirical data and the simulated data. The artificial data was produced by 100 runs of the described model.

4.4 Bands of the normal capacity utilization rate for individual sectors

Given the calibration and verification of the model in the previous sections 3 and 4, the model can be used to show the range of values for the normal rate of capacity utilization at the sectoral level. In this way, the model 'predicts' a band of values for the normal rate of capacity utilization in each sector.

For this purpose, the model is simulated separately for each sector for 47 periods.[18] A total of 250 simulation runs is performed for each sector.[19] To obtain the range of values for each sectoral normal capacity utilization rate, we abstain from making purely random draws from the sector-specific log-normal distributions of $\sigma_t^{i,j}$, as in the simulations performed in section 4.2. Instead, we assume greater regularity in fluctuations in volatility as observed in the data (Setterfield and Avritzer, 2019; Jurado et al., 2015). Specifically, we model low volatility for around 20 consecutive periods by randomly drawing low values from the sector-specific log-normal distribution to simulate volatility during long booms. We then model high volatility for around five subsequent periods by randomly drawing high values from the sector-specific log-normal distribution to simulate crisis conditions (Setterfield and Avritzer, 2019). Both regimes are simulated with plus (minus) a random draw of η periods (with $\eta \sim U[-3;3]$) to account for randomness in the duration of long booms and crises. As mentioned above (section 4.1), firms are inclined to respond quickly to crises as confidence is suddenly fractured. Pessimistic perceptions are more persistent, however, consistent with the more drawn-out process of 'forgetting the last crisis'. This delays the recovery of 'boom time' behavior as confidence is only slowly restored (Irons, 2009).

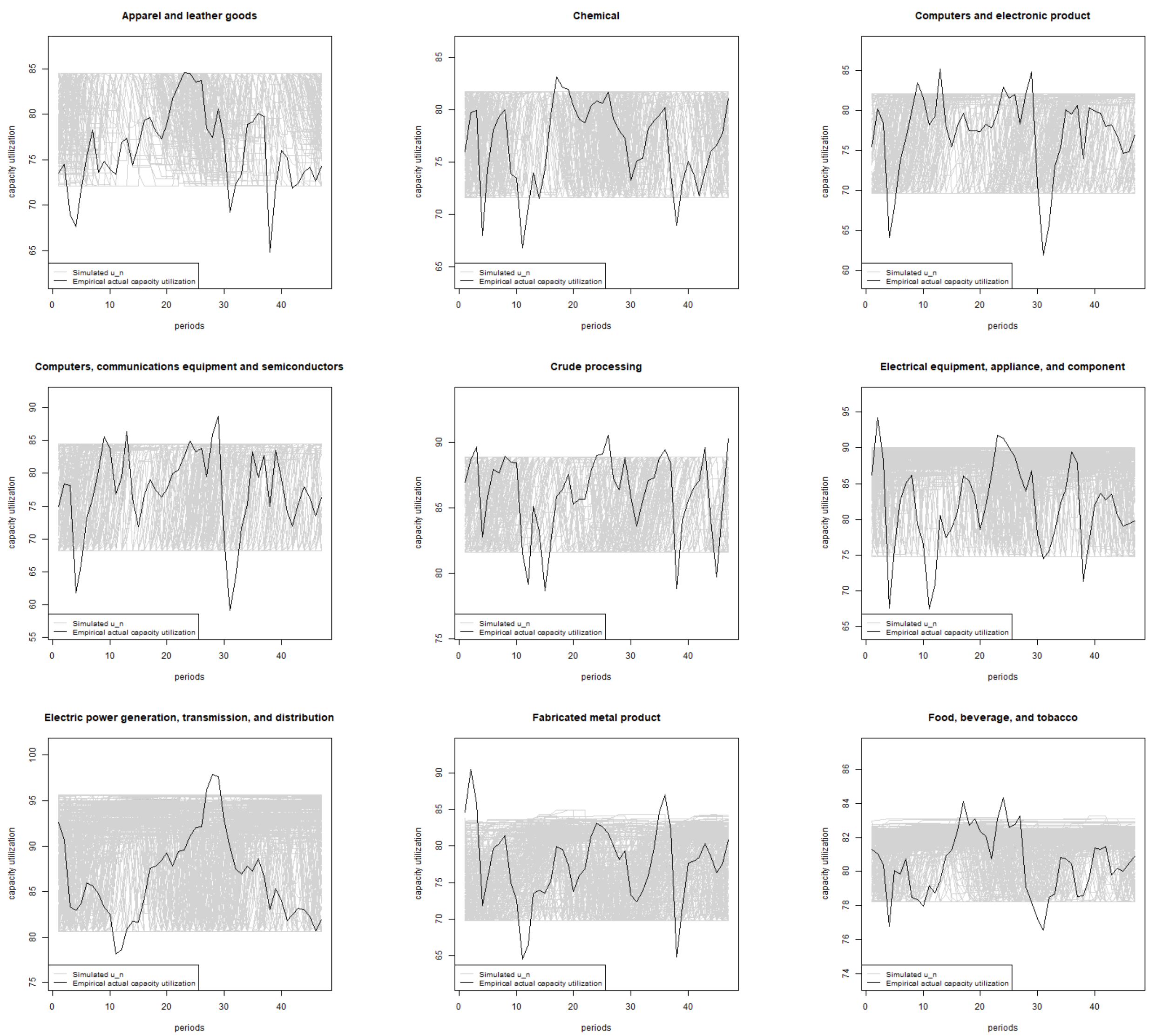
The results of the simulations are depicted in figures 6, 7 and 8 as the grey lines. The figures further contain the empirical, detrended, time series of the actual rate of capacity utilization, depicted as the black line. As the figures show, the bands of the normal rate of capacity uti-

[18]Model is simulated for 121 periods. We present only the last 47 periods of each run. The remaining 74 periods are used as a burn-in phase.

[19]To simulate 250 runs implies to simulate the model for 250 simulations, each with a specific random seed.

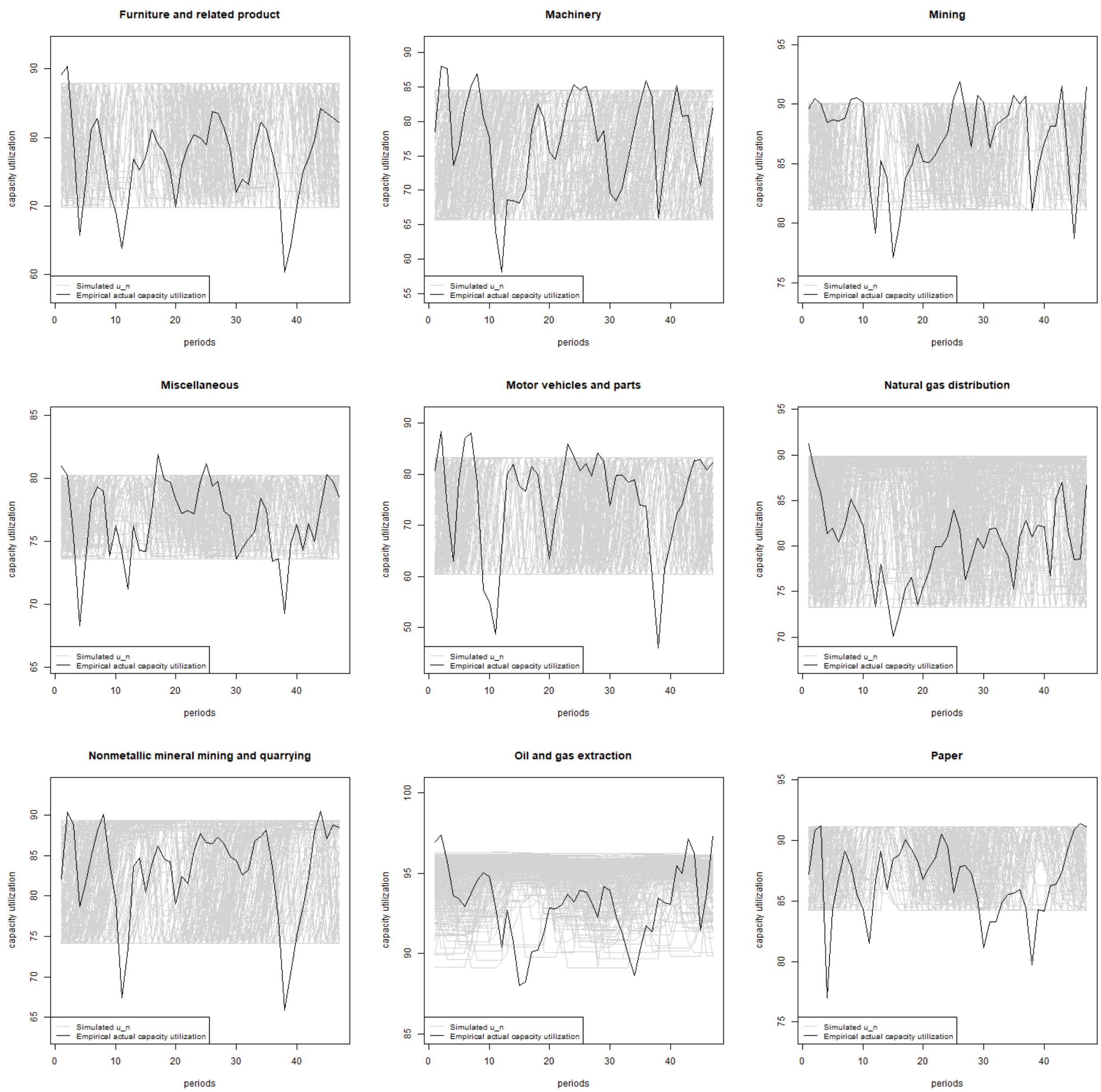
lization are always located between the extrema of the actual rate of capacity utilization. In other words, the normal rate of capacity utilization varies between a smaller range of values than the actual rate. The figures show that, typically, the bands are more densely populated in their upper echelons, closer to the upper bound u_{nH}. This implies that most industries operate most frequently rather closer to u_{nH} than to u_{nL}. To some extent this result is intuitive: by design, our simulations involve long periods of tranquility punctuated by short periods of crisis, so that the frequency of events that might encourage a firm initially operating at u_{nH} to switch to u_{nL} is substantially less than the frequency of events that would encourage the firm to maintain operations at u_{nH}. Nevertheless, figures 6, 7 and 8 exhibit considerable heterogeneity among sectors with respect to the 'density' of the interval over which u_n varies. The computer sector (*Computers and electronic products* and *Computers, communications equipment, and semiconductors*), fossil fuel industries (*Oil and gas extraction* and *Natural gas distribution*), and the electricity sector (*Electrical equipment, appliance, and component* and *Electric power generation, transmission, and distribution*) operate much less frequently at or near to u_{nL} than do other sectors. Meanwhile, some industries operate rather below the upper bound of u_n, such as *Fabricated metal products*. This sector is instead characterized by a dense band in the middle of the graphic in figure 6. Notice also that the various industries differ quite substantially with respect to the range of values of u_n within which they operate. On the one hand, the normal rates of capacity utilization are generally quite high (i.e. high u_{nH} and high u_{nL}) among industries that use products from the primary sector, such as the *Mining* and *Paper* sectors. However, other industries operate within a much wider range of values of u_n (e.g., *Plastics and rubber products, Machinery* and *Non-metallic mineral mining and quarrying*).

Figure 6: Band of normal capacity utilization and upper and lower bound of actual capacity utilization



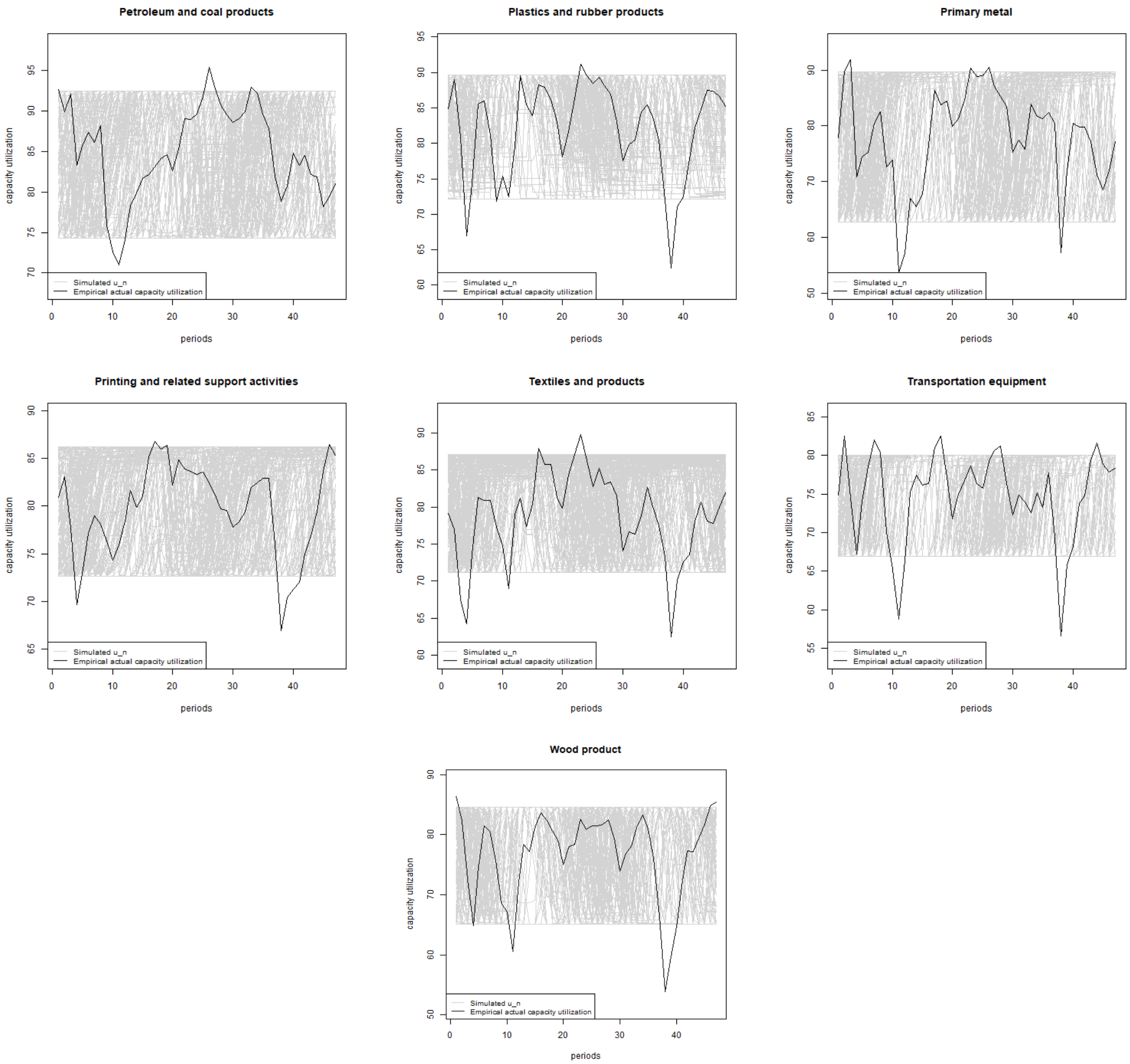
The grey lines show the simulations of the model for each sector. The model was simulated over 47 periods (121 period minus 75 burn-in periods) and 250 random seeds. The black lines show the (detrended) actual rate of capacity utilization.

Figure 7: Band of normal capacity utilization and upper and lower bound of actual capacity utilization



The grey lines show the simulations of the model for each sector. The model was simulated over 47 periods (121 period minus 75 burn-in periods) and 250 random seeds. The black lines show the (detrended) actual rate of capacity utilization.

Figure 8: Band of normal capacity utilization and upper and lower bound of actual capacity utilization



The grey lines show the simulations of the model for each sector. The model was simulated over 47 periods (121 period minus 75 burn-in periods) and 250 random seeds. The black lines show the (detrended) actual rate of capacity utilization.

5 Discussion and interpretation

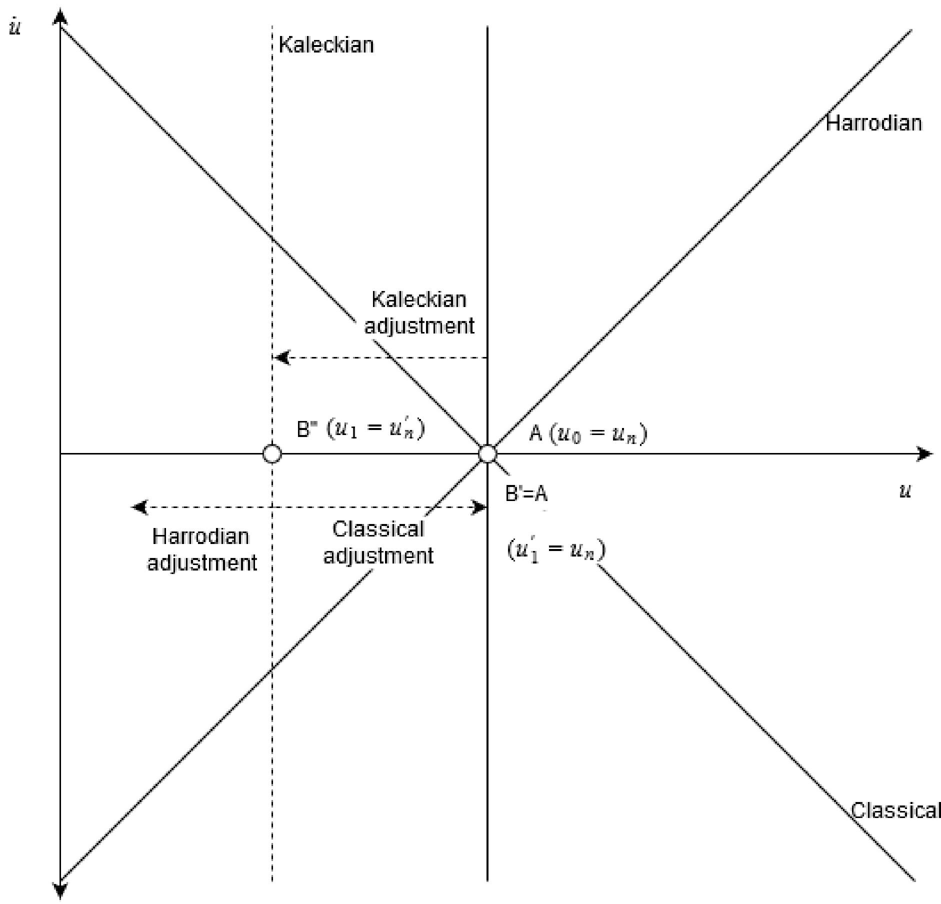
5.1 Modeling hysteresis in the normal rate of capacity utilization

So far, we have modeled genuine hysteresis in a manner that is true to its heterogeneous agent micro-structure: each firm in each sector of the economy is characterized by an idiosyncratic non-ideal relay. The question that might be asked is: to what end? What is the 'payoff' to providing proper microfoundations for the process of hysteresis?

One result of paying attention to the micro-structure of genuine hysteresis is clearly evident from figures 6 – 8: *discrete* switching between high and low values of u_n at the micro (firm) level creates *continuous* variation in u_n at the sectoral level. In figures 6 – 8, this continuous variation is represented by what, by virtue of the number of simulations plotted in each figure, appear as the 'shaded' zones or bands of adjustment of the normal rate. Although not surprising in and of itself, this result (discrete adjustment at the micro-level giving rise to continuous adjustment in the aggregate owing to heterogeneity at the micro level) has important implications. Hence note that our model is behaviorally akin to that of Setterfield and Avritzer (2019) in terms of its microstructure, insofar as the normal rate of utilization at firm-level is strictly single-valued, and can only vary discretely between two (upper and lower) values in response to more or less volatile goods market environments. But our aggregate (sectoral) results are akin to those found in Dutt (2010), Setterfield (2019) and Botte (2019), where $u_n = \bar{u}_n \pm c$ (where c is some constant) is interpreted as an *interval*. Similar to the results associated with these interval models, we see $\Delta u > \Delta u_n$ in figures 6 – 8 (Setterfield, 2019; Botte, 2019). Taken together, the results of both our own model and the interval models suggest a consensual vision of the possibility of discretely different macrodynamics operating over different ranges of variation in the actual rate of capacity utilization. This is illustrated in figure 9. Figure 9 illustrates three adjustment regimes that can be experienced by an economy that begins at point A with $u_0 = u_n$: a stable Classical regime where $\dot{u} = f(u - u_n)$ such that $f' < 0$; an unstable Harrodian regime where $\dot{u} = g(u - u_n)$ such that $g' > 0$; and a hysteretic Kaleckian regime where $\dot{u}_n = h(u - u_n)$ with $h' > 0$. Now consider an economy beginning at point A ($u_0 = u_n$) that is subject to a shock that displaces the economy to point B$''$ where $u_1 < u_0 = u_n$. In the Classical regime, u will adjust to $u_1' = u_0 = u_n$ and in so doing the economy is returned to equilibrium at point B$'$ = A. In the Harrodian regime, u will will continue to fall in a series of self-reinforcing adjustments that give expression to Harrodian instability. Finally, in the Kaleckian regime, u_n adjusts to $u_n' = u_1$, and equilibrium is restored at point B$''$. In the model developed in this paper, however, $u_1 = u_n'$ may represent an outer limit to the Kaleckian regime. If so, any future disturbance that results in $u < u_1 = u_n'$ will leave the normal rate of utilization unchanged, and instead be either self-correcting (as u returns to u_n' in accordance with the Classical dynamic) or self-reinforcing (as u falls ever further below u_n' in accordance with the Harrodian dynamic). In this way, u_n' is revealed as a boundary or threshold separating Kaleckian dynamics from qualitatively different Classical and/or Harrodian dynamics, in an economy that may display Classical, Harrodian, or Kaleckian adjustment dynamics over different ranges of variation in the actual rate of capacity utilization.

Unlike interval models of u_n, however, the 'density' of the interval over which u_n varies in figures 6 – 8 is, itself, variable, and to an extent that differs between sectors of the economy. Hence as previously remarked, in several sectors (see, for example, *Electrical equipment, appliance, and component* or *Computers and electronic product*) this density is observably greater nearer the upper bound of the interval of the normal rate (u_{nH}) than it is nearer to the lower bound of the interval (u_{nL}). In other words, in some sectors of the economy and with high frequency (across the number of simulations used to generate the results in figures 6 – 8), the value of u_n typically 'tracks closer' to u_{nH} than to u_{nL}, so that the hysteretic value of the normal rate across a large number of simulations 'clusters' closer to u_{nH} than to u_{nL}, regardless of the observed variation in u. This means that, with relatively high frequency (as compared with sectors such as *Apparel and leather goods* or *Machinery*, where the density of the interval over which u_n varies is more uniform over the entire range of the interval), we can expect to observe $u_n > u_{nL}$

Figure 9: Classical, Harrodian and (modified) Kaleckian adjustment



even as $u_{nL} < u < u_n$ for most firms in the sector, indicating a *lack of adjustment* of u_n towards u even within the plausible range of adjustment determined by the interval $u_{nH} - u_{nL}$. This is significant because it suggests a limit to the adjustment of u_n within some sectors of the economy that is not predicted by interval models of the natural rate of capacity utilization, which effectively suggest that $u = u_n$ is satisfied for all u such that $u_{nL} = \bar{u}_n - c \leq u \leq \bar{u}_n + c = u_{nH}$.

The observations above point to the value of modeling hysteresis in the normal rate in accordance with genuine hysteresis *and* in a manner faithful to the precise *microfoundations* of the latter: substantive results (and their behavioral implications) clearly differ between such a model and either single-sector genuine hysteresis models or interval models of the normal rate.

5.2 Implications for aggregate structural modeling

In order to take account of sector-specific dynamics and the possibility of genuine hysteresis in the normal rate of capacity utilization, aggregate structural models should always be augmented by an agent-based block akin to the one developed in this paper. Nevertheless, single-sector aggregate structural models remain popular in macrodynamics and with good reason, given the ease with which they can be manipulated to clearly demonstrate cause-effect interactions between variables in a domain in which causality is the key issue. Recall also that according to Setterfield (2009), it is possible to adopt a 'hybrid' or pragmatic approach to modeling hysteresis based on the methodological question ('how complicated does the model need to be?') associated with authors such as Krugman (2000). The question thus arises: are there lessons from the microfounded model of genuine hysteresis developed in this paper that can be incorporated into single-sector, aggregate structural models, and that would thereby improve 'pragmatic' single sector models of 'hysteresis' based on aggregate, linear difference (or differential) equations? We would argue that there are, so that, to the extent that the debate about hysteresis in the normal rate of capacity utilization continues to make use of single-sector models, these models can be improved by reference to the results of and insights developed in this paper.

First, note once again that $\Delta u > \Delta u_n$ in figures 6 – 8: the range of variation in u exceeds the range of variation in u_n even if the latter is represented as the interval $u_{nH} - u_{nL}$,[20] and will do so by a greater margin if the variation in the 'density' of this interval is taken into account, so that the 'effective' value of u_{nL} (based on the infrequency with which u_n can be found approximating its lower limit) is thought to lie above its actual value. This suggests that as a first approximation, we might write:

$$\Delta u_n = \alpha \Delta u \tag{13}$$

where α denotes the 'degree of hysteresis in the normal rate' – i.e., the fraction of any change in the actual rate of utilization between high and low volatility macro regimes that we would usually expect to see reflected in change in the normal rate of capacity utilization. Here, the hysteresis effect is partial, reflecting only some fraction of Δu.

Now recall that in the Kaleckian literature, it is common to posit two alternative (Classical/neo-Keynesian and Kaleckian) closures:

$$u_n = \bar{u}_n \tag{1}$$

and:

$$\dot{u}_n = \beta(u - u_n) \tag{2}$$

In this approach, hysteresis is either non-existant ($\alpha = 0$ as in the Classical/neo-Keyensian closure in equation (1)) or else complete ($\alpha = 1$ as in the Kaleckian closure in equation (2)). But on the basis of our results ($0 < \alpha < 1$), a *third* closure would appear to be merited,[21] that reflects the

[20] See also the interval models of Setterfield (2019) and Botte (2019) for similar results.
[21] This claim is also consistent with interval models of u_n such as Setterfield (2019) and Botte (2019).

(partial) degree of hysteresis and that, in a one-sector structural model context can be captured by simultaneous operation of both:

$$\dot{u}_n = \beta(u - u_n) \tag{2}$$

and:

$$\dot{u} = -\delta(u - u_n) \tag{14}$$

In this third *modified Kaleckian* closure, the final change in u_n (when the economy is restored to a fully-adjusted steady-state equilibrium) is non-zero but smaller than the initial change in u, consistent with the degree of hysteresis being partial ($\Delta u_n = \alpha \Delta u$ where $\alpha < 1$). This modeling innovation, in turn, merits two further comments. First, the degree of hysteresis can be related to the relative size of the speed of adjustment parameters β and δ in equations (2) and (14). Suppose, for example, that $\alpha = 0.5$, so that following a departure of u from u_n creating an initial interval of size $u - u_n$, u and u_n adjust so as to eventually 'meet in the middle' of the interval. This will result from identical speeds of adjustment, $\beta = \delta$. If we were to observe $\alpha = 0.33$, meanwhile, u must be adjusting twice as fast towards u_n as u_n is adjusting towards u, so $\delta = 2\beta$. In general:

$$\frac{\beta}{\delta} = \frac{1-\alpha}{\alpha}$$

$$\Rightarrow \alpha = \frac{\delta}{\beta + \delta} \tag{15}$$

The degree of hysteresis, α, can therefore be inferred from the speeds of adjustment in (2) and (14) and is therefore (in principle) empirically observable.

Second, the operation of the modified Kaleckian closure in a standard, one-sector Kaleckian model could be captured by the simultaneous operation of equations (2) and a second differential equation that, together with a simplified Kaleckian investment function describing the rate of accumulation (g) as:

$$g = \gamma + f(u) \tag{16}$$

describes the intercept term γ adjusting as:

$$\dot{\gamma} = -\eta(u - u_n) \tag{17}$$

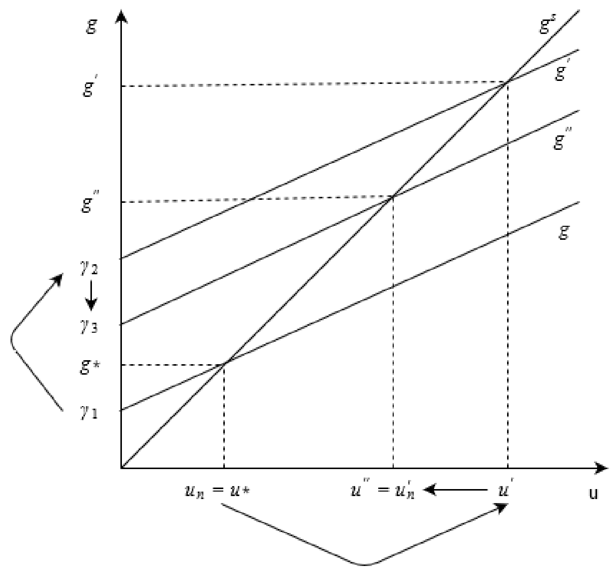
The simultaneous operation of the mechanisms in equations (16) and (17) is illustrated in figure 10, where the basic structure of the Kaleckian model is represented by the investment schedule g (based on equation (16)) together with the relationship $g^s = s_\pi \pi u$, where s_π denotes the propensity to save from profits and π is the profit share of income. The model is depicted in an initial state of equilibrium at $u^* = u_n$, consistent with the growth rate g'.

Now consider an initial increase in γ from γ_1 to γ_2 that raises u to $u' > u^* = u_n$. Consistent with (2), the value of u_n will begin to rise. But consistent with (17), the value of γ will begin to fall, shifting the g schedule downwards and, in so doing, reducing the equilibrium value of u towards u_n. In this way, the response of γ to $u \neq u_n$ in equation (17) brings about variations in u consistent with equation (14). A fully adjusted steady state equilibrium is restored when $\gamma = \gamma_3$, where $u'' = u'_n$ at the accompanying growth rate g''.

6 Conclusions

This paper contributes to the current literature in four respects. First, we find evidence supportive of the hypothesis that there is genuine hysteresis in the normal rate of capacity utilization at sectoral level in the US economy. It should be noted, however, that our analysis provides only partial support for this hypothesis: some sectors of the US economy do not display the statis-

Figure 10: Hysteresis in the normal rate of capacity utilization: the modified Kaleckian closure



tical regularities consistent with the discrete switching between higher and lower values of the normal rate that can be associated with genuine hysteresis in the latter.

Second, by developing and applying a simple agent-based model, we are able to make suggestions about the industry-specific behaviour of normal rates of capacity utilization. Our model shows that discrete variations in the normal rate of capacity utilization (between'higher' and 'lower' values $u_{nH}^{i,j}$ and $u_{nL}^{i,j}$) at firm-level result in relatively smooth (i.e., continuous) changes in the normal rate at sectoral level, as captured in figures 6 – 8. Furthermore, our simulations demonstrate that different sectors of the US economy operate at quite different normal rates of capacity utilization. For example, while some sectors appear to operate at consistently high normal rates, others oscillate within a rather wide range of values. In all cases, however, the ranges of variation in the normal rate of capacity utilization are smaller than the corresponding ranges of variation in the actual rate. This is true even though these ranges of variation are small in some sectors.

Third, our simulation exercises have important implications for heterodox macrodynamics.

Our results suggest that the normal rate of utilization varies endogenously within a range that is a subset of the full range of observed variation in the actual rate of capacity utilization. In other words, the normal rate can be regarded as *partially* hysteretic. Ultimately, then, our model suggests that there is a corridor, defined by that part of the range of variation in the actual rate of capacity utilization for which we observe hysteretic variation in the normal rate, within which the mechanisms of Kaleckian macrodynamics are operative.

Finally, and reflecting more broadly on Post Keynesian macroeconomics as a whole, this paper suggests a route towards possible reconciliation of work in the Classical/neo-Keynesian and Kaleckian traditions. Our partial hysteresis result is suggestive of an economy in which both Classical/neo-Keynesian and Kaleckian adjustment mechanisms are operative. In a traditional (one sector) model, this can be captured by disequilibrium dynamics that involve a double and simultaneous adjustment process in which the actual rate of capacity utilization adjusts towards the normal rate and the normal rate of capcity utilization adjusts towards the actual rate. It follows from these observations that the opportunity exists for greater synthesis of these seemingly competing traditions.

These contributions aside, our analysis leaves open various avenues for further investigation and research. For example, our simulation model would benefit from firm-level data that would still more firmly anchor our claims about hysteresis in the normal rate in the empirical properties of the US economy. Furthermore, and as noted in sub-section 5.2, proper integration of genuine hysteresis in the normal rate into Post Keynesian macrodynamics requires augmenting an aggregate structural model with the sort of agent-based block developed in this paper. Only the completion of this task will provide a model of long-run variation in the normal rate of capacity utilization in a manner consistent with the properties of genuine hysteresis. Finally, in addition to calling for further integration of genuine hysteresis into Post Keynesian macrodynamics (consistent with the traditions initiated by both Robinson (1962, chpt. 2) and Kaldor (1972)), our paper suggests that future research should pay more attention to thinking of Classical/neo-Keynesian and Kaleckian macrodynamics as being potentially characteristic of different historical regimes of capitalism, rather than as opposing theories of unvarying (historically uniform) capitalist macrodynamics.

It is also worth remarking that our research has implications for policy. As is well known, variability in the rate of capacity utilization is a necessary condition for the Kaleckian paradox of costs. To the extent that the normal rate of capacity utilization displays hysteresis over a subset of the range of variation in the actual rate of capacity utilization, this suggests that progressive policies designed to redistribute income towards wages can be conducive to improved long-run macroeconomic performance that, by simultaneously raising the rate of profit, avoids distributional conflict. Because hysteretic variation in the normal rate of utilization is not universal, however, neither is the argument just made: progressive policies of income redistribution cannot be considered a panacea for modern capitalism. Of course, redressing income inequality is not simply a means to an end. But to the extent that serving the objective of improved long-run macroeconomic performance strengthens the case for redressing income inequality, our paper can be thought of as lending credence to the notion that redistributing income towards wages can be beneficial because of its potentially positive contribution to the performance of the economy.

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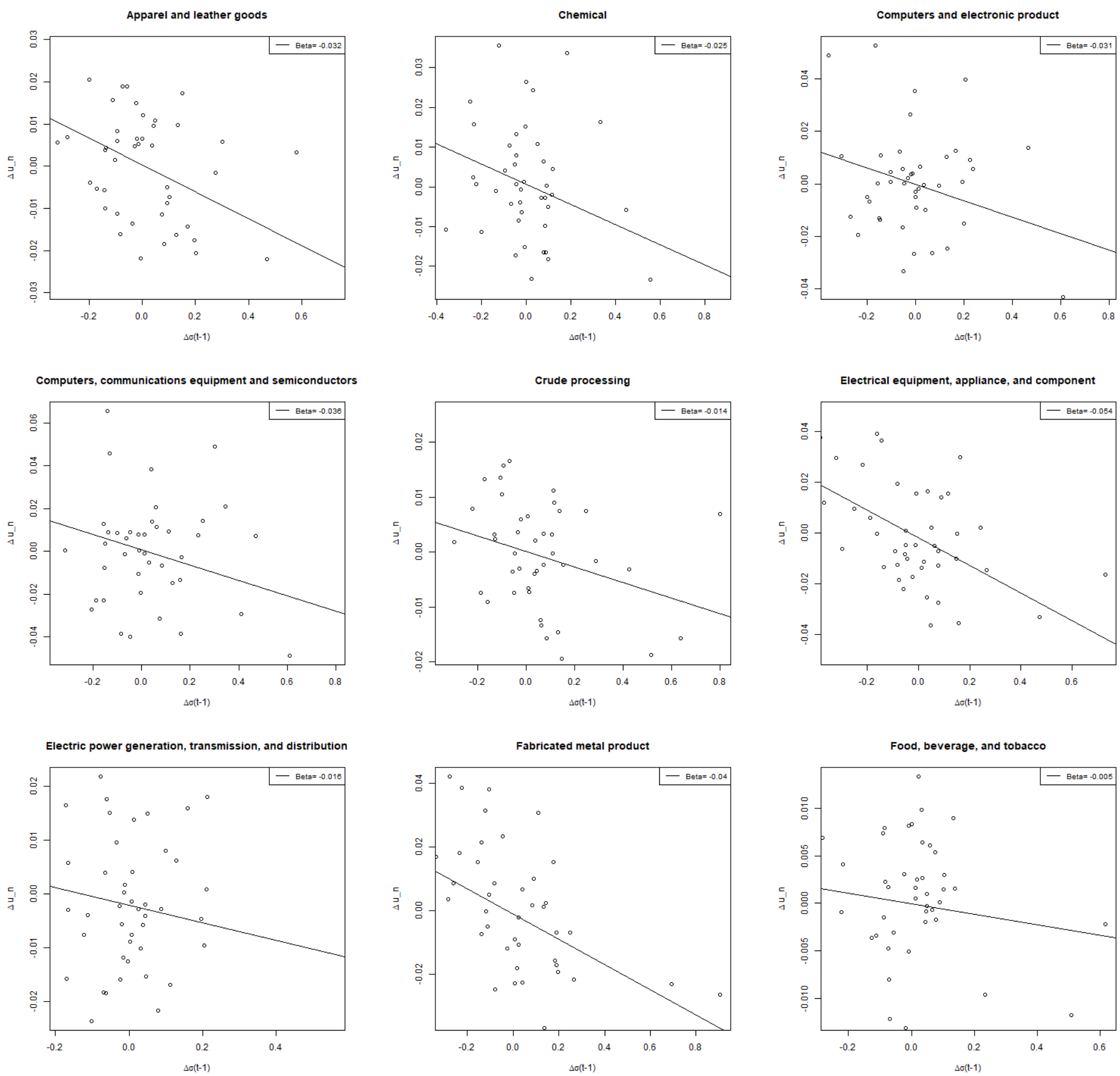
7 Appendix

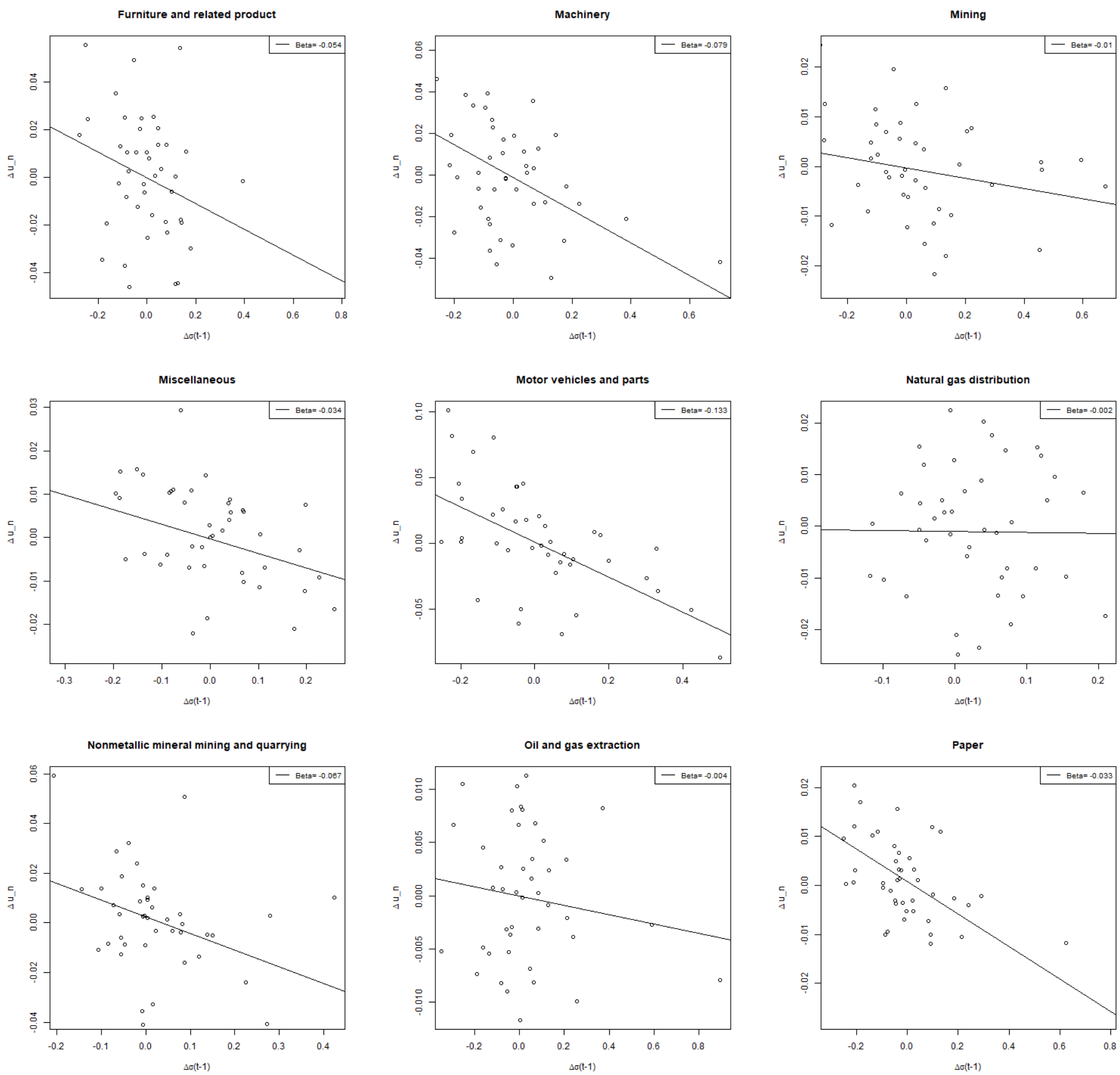
7.1 Sectoral correlation between Δu_n and $\Delta \sigma_{t-1}$

Figure 11: Correlation between Δu_n and $\Delta \sigma_{t-1}$



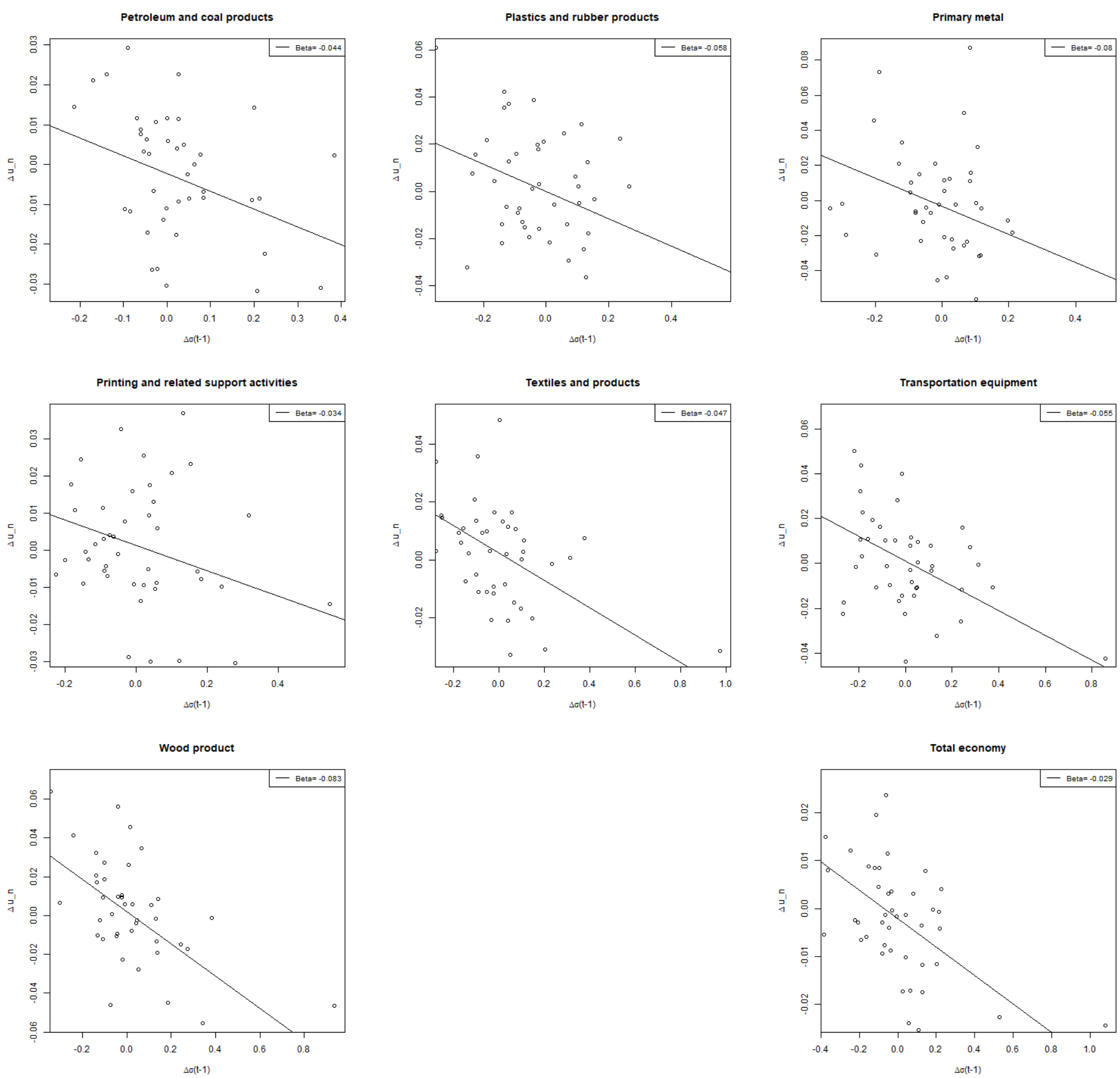
Description: Figures depict the scatter plots for the sector-specific relation between the changes in u_n and changes in σ_{t-1}. They show a negative relationship between both variables for all sectors. The slope parameter (β) is always below 1, which indicates that u_n responds to changes in σ_{t-1}, but to a lower extent than the changes in σ_{t-1}.

Figure 12: Correlation between Δu_n and $\Delta\sigma_{t-1}$ on sectoral level



Description: Figures depict the scatter plots for the sector-specific relation between the changes in u_n and changes in σ_{t-1}. They show a negative relationship between both variables for all sectors. The slope parameter (β) is always below 1, which indicates that u_n responds to changes in σ_{t-1}, but to a lower extent than the changes in σ_{t-1}.

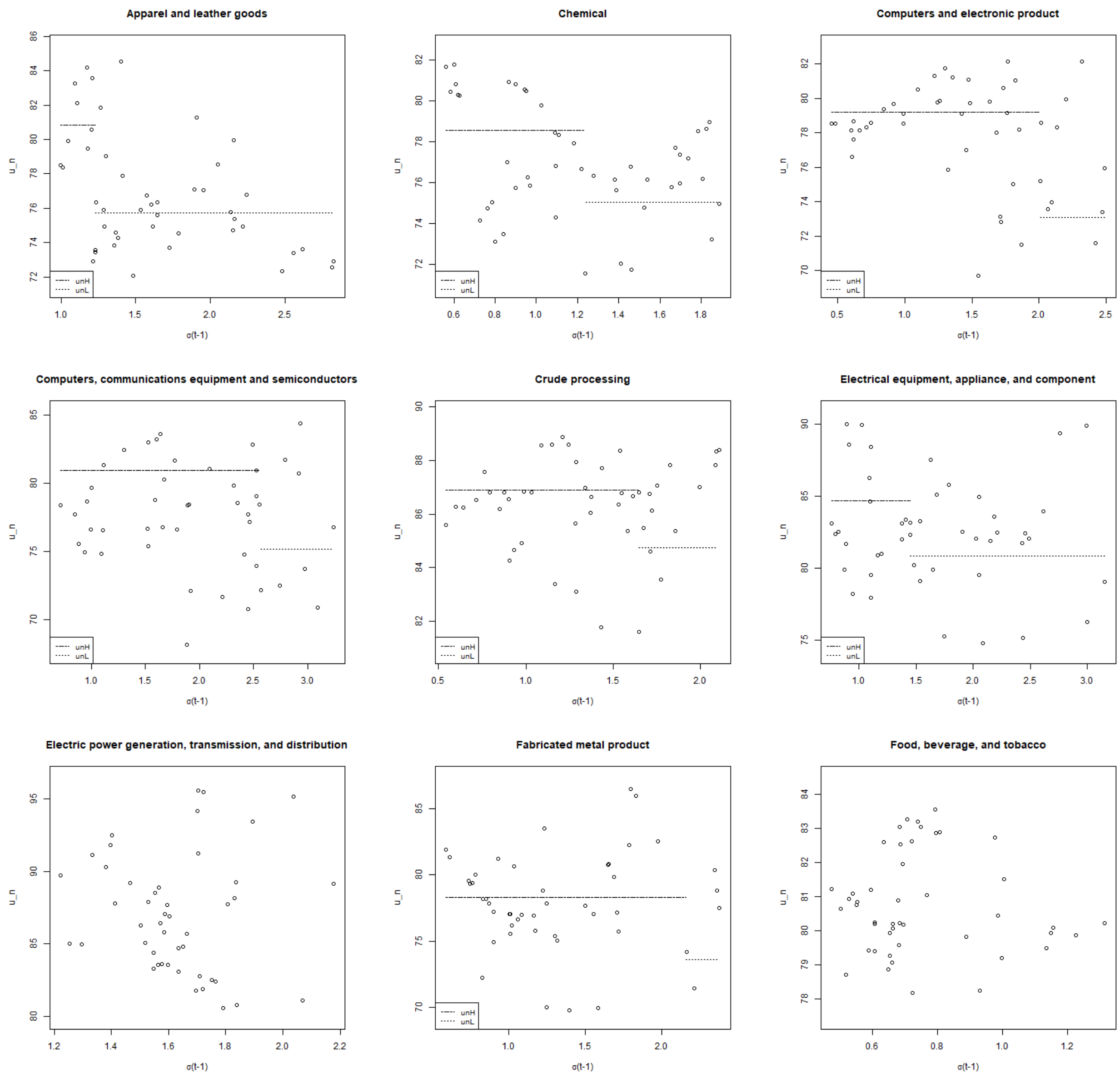
Figure 13: Correlation between Δu_n and $\Delta\sigma_{t-1}$ on sectoral and macroeconomic level



Description: Figures depict the scatter plots for the sector-specific relation between the changes in u_n and changes in σ_{t-1}. They show a negative relationship between both variables for all sectors. The slope parameter (β) is always below 1, which indicates that u_n responds to changes in σ_{t-1}, but to a lower extent than the changes in σ_{t-1}.

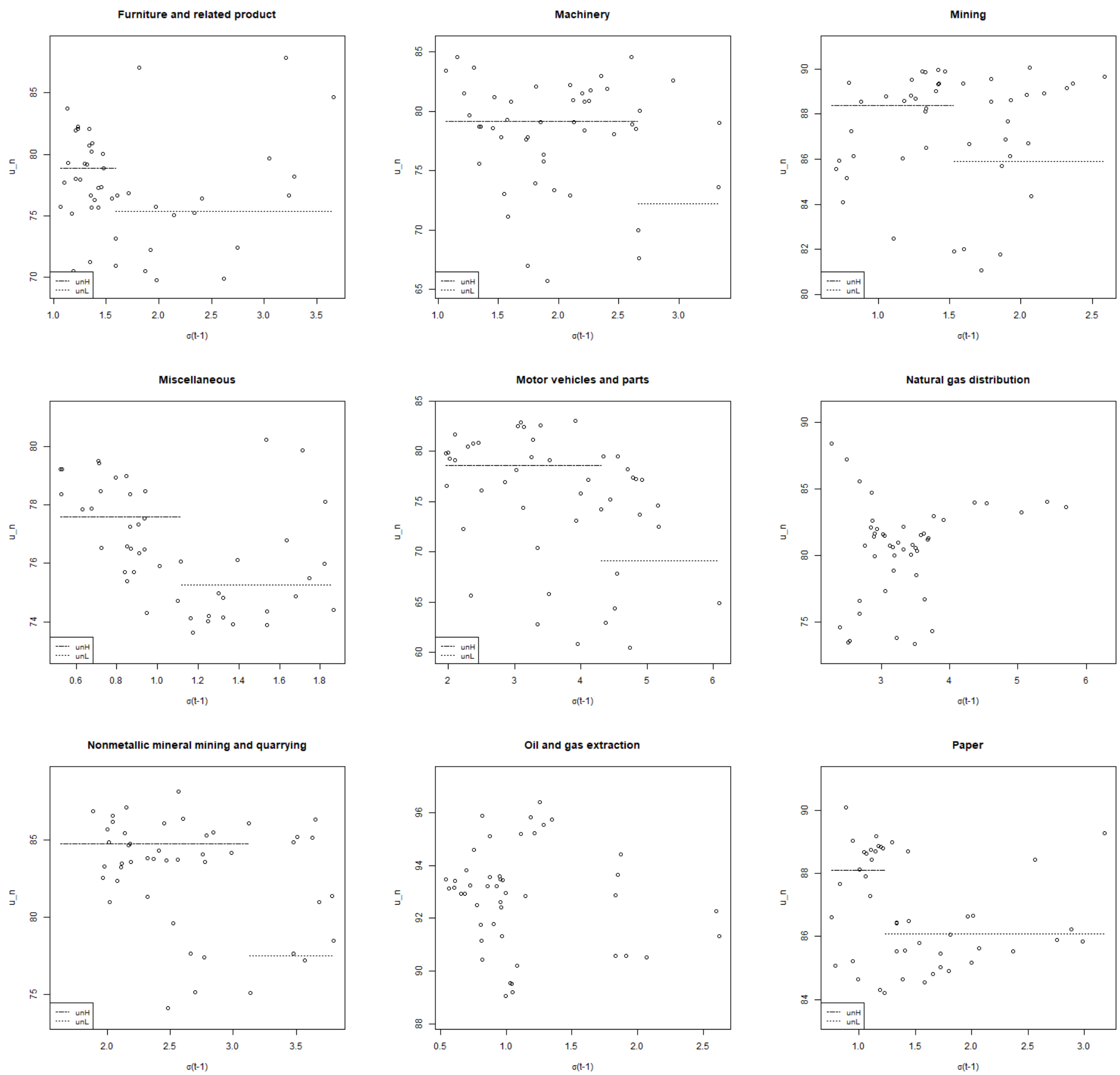
7.2 Sectoral scatter plots u_n and σ_{t-1}

Figure 14: Sectoral scatter plot u_n and σ_{t-1} (including u_{nL} and u_{nH})



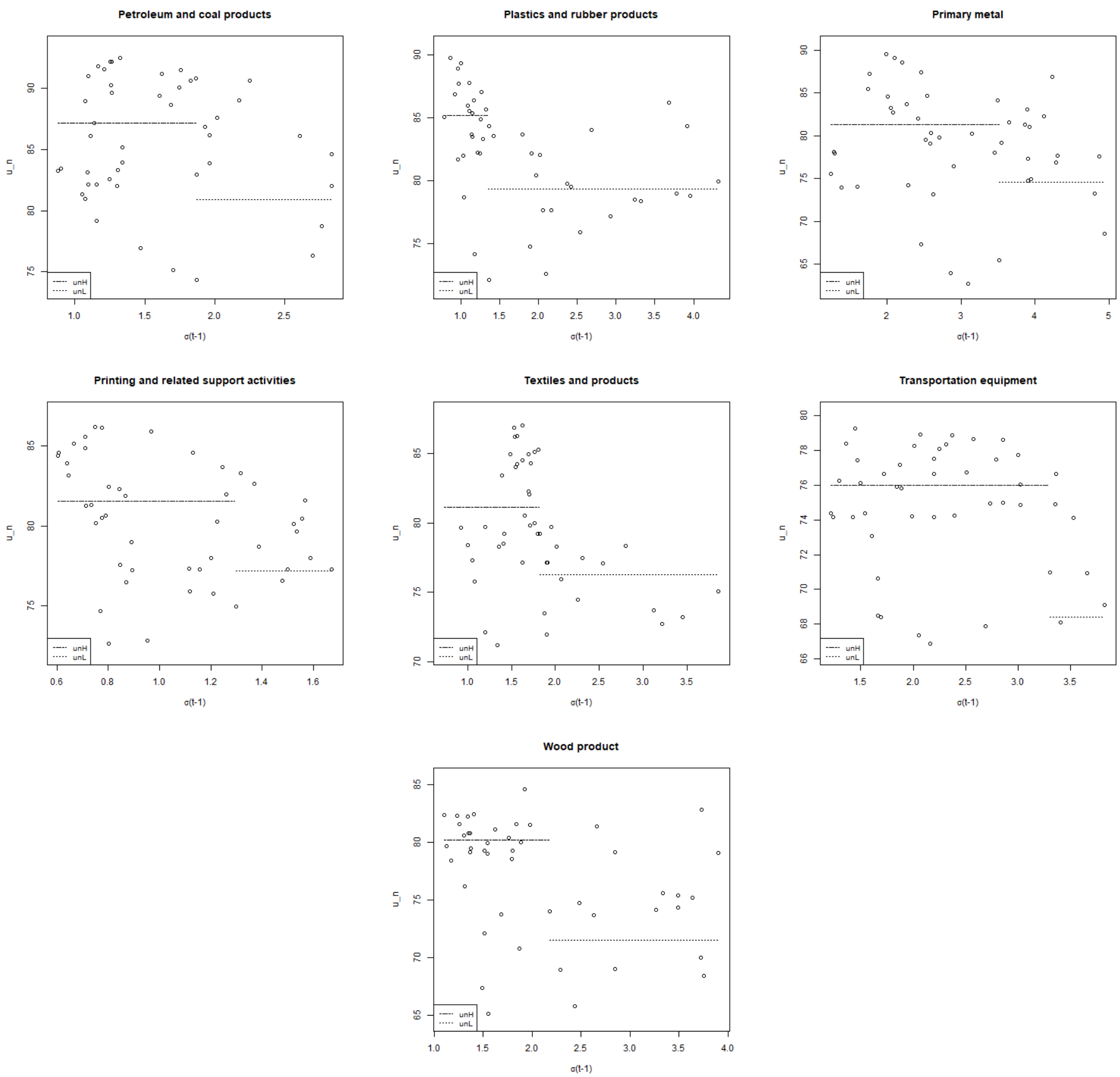
The figures show the scatter plots for the sector-specific u_n and σ_{t-1}. Further, these graphs depicts the upper and lower rate of u_n (u_{nH} and u_{nL}).The sectors *Electric power generation, transmission and distribution* and *Food, beverage and tobacco* do not show u_{nL} and u_{nH} because the discrete threshold regression model could not find significant thresholds.

Figure 15: Sectoral scatter plot u_n and σ_{t-1} (including u_{nL} and u_{nH})



The figures show the scatter plots for the sector-specific u_n and σ_{t-1}. Further, these graphs depicts the upper and lower rate of u_n (u_{nH} and u_{nL}). The sectors *Natural gas distribution* and *Oil and gas extraction* do not show u_{nL} and u_{nH} because the discrete threshold regression model could not find significant thresholds.

Figure 16: Sectoral scatter plot u_n and σ_{t-1} (including u_{nL} and u_{nH})



The figures show the scatter plots for the sector-specific u_n and σ_{t-1}. Further, these graphs depicts the upper and lower rate of u_n (u_{nH} and u_{nL}).

7.3 Correlation structure of σ between sectors

Table 5: Correlation structure

	Apparel and Leather Goods	Chemical	Computer and electronic product	Computers, communications equipment, and semiconductors	Crude processing	Electrical equipment appliance and component
Apparel and leather goods	1	0.327	0.505	0.471	0.273	0.383
Chemical	0.327	1	0.26	0.223	0.688	0.686
Computer and electronic product	0.505	0.26	1	0.927	0.192	0.537
Computers, communications equipment, and semiconductors	0.471	0.223	0.927	1	0.172	0.437
Crude processing	0.273	0.688	0.192	0.172	1	0.464
Electrical equipment, appliance, and component	0.383	0.686	0.537	0.437	0.464	1
Electric power generation, transmission, and distribution	0.141	0.007	0.335	0.312	-0.013	0.175
Fabricated metal product	0.501	0.677	0.408	0.307	0.477	0.797
Food, beverage and tobacco	0.273	0.297	0.188	0.145	0.273	0.201
Furniture and related products	0.396	0.588	0.395	0.305	0.247	0.695
Machinery	0.474	0.314	0.35	0.241	0.455	0.636
Mining	0.126	0.518	0.06	0.05	0.919	0.326
Miscellaneous	0.343	0.54	0.298	0.226	0.414	0.659
Motor vehicles and parts	0.173	0.402	0.028	0.02	0.106	0.521
Natural gas distribution	0.041	-0.116	-0.117	-0.132	-0.104	-0.199
Non-metallic mineral product	-0.012	0.484	0.146	0.18	0.435	0.433
Oil and gas extraction	-0.005	0.496	-0.022	0.058	0.618	0.124
Paper	0.506	0.662	0.241	0.2	0.333	0.608
Petroleum and coal products	0.121	0.64	0.18	0.113	0.499	0.539
Plastics and rubber products	0.323	0.598	0.308	0.23	0.12	0.628
Primary metal	0.368	0.727	0.207	0.097	0.555	0.652
Printing and related support activities	0.423	0.489	0.411	0.373	0.408	0.597
Textiles and products	0.52	0.531	0.216	0.154	0.197	0.522
Transportation equipment	0.22	0.496	0.07	0.1	0.304	0.522
Wood product	0.214	0.693	0.265	0.223	0.316	0.678

Table 6: Correlation structure (Cont.)

	Electric Power Generation, Transmission, and Distribution	Fabricated Metal Product	Food, Beverage and Tobacco	Furniture and Related Products	Machinery	Mining
Apparel and leather goods	0.141	0.501	0.273	0.396	0.474	0.126
Chemical	0.007	0.677	0.297	0.588	0.314	0.518
Computer and Electronic Product	0.335	0.408	0.188	0.395	0.35	0.06
Computers, communications equipment, and semiconductors	0.312	0.307	0.145	0.305	0.241	0.05
Crude processing	-0.013	0.477	0.273	0.247	0.455	0.919
Electrical equipment, appliance, and component	0.175	0.797	0.201	0.695	0.636	0.326
Electric power generation, transmission, and distribution	1	0.12	-0.08	-0.002	0.28	-0.055
Fabricated metal product	0.12	1	0.161	0.577	0.698	0.321
Food, beverage and tobacco	-0.08	0.161	1	0.374	0.035	0.154
Furniture and related products	-0.002	0.577	0.374	1	0.323	0.109
Machinery	0.28	0.698	0.035	0.323	1	0.377
Mining	-0.055	0.321	0.154	0.109	0.377	1
Miscellaneous	0.175	0.681	0.198	0.559	0.7	0.341
Motor vehicles and parts	0.212	0.454	0.081	0.457	0.309	0.09
Natural gas distribution	0.182	-0.07	-0.082	-0.16	-0.009	-0.12
Non-metallic mineral product	0.038	0.436	0.091	0.407	0.172	0.361
Oil and gas extraction	-0.051	0.273	-0.058	-0.052	0.042	0.484
Paper	-0.158	0.564	0.388	0.742	0.294	0.207
Petroleum and coal products	-0.1	0.56	0	0.509	0.292	0.402
Plastics and rubber products	0.05	0.56	0.217	0.655	0.232	0.01
Primary metal	0.004	0.731	0.161	0.495	0.572	0.425
Printing and related support activities	0.075	0.59	0.255	0.457	0.354	0.267
Textiles and products	-0.154	0.498	0.423	0.804	0.268	0.049
Transportation equipment	0.057	0.486	0.003	0.379	0.231	0.281
Wood product	-0.141	0.572	0.262	0.716	0.222	0.183

Table 7: Correlation Structure (Cont.)

	Miscellaneous	Motor Vehicles and Parts	Natural Gas Distribution	Non-metallic mineral product	Oil and Gas Extraction	Paper
Apparel and leather goods	0.343	0.173	0.041	-0.012	-0.005	0.506
Chemical	0.54	0.402	-0.116	0.484	0.496	0.662
Computer and electronic product	0.298	0.028	-0.117	0.146	-0.022	0.241
Computers, communications equipment, and semiconductors	0.226	0.02	-0.132	0.18	0.058	0.2
Crude processing	0.414	0.106	-0.104	0.435	0.618	0.333
Electrical equipment, appliance, and component	0.659	0.521	-0.199	0.433	0.124	0.608
Electric power generation, transmission, and distribution	0.175	0.212	0.182	0.038	-0.051	-0.158
Fabricated metal product	0.681	0.454	-0.07	0.436	0.273	0.564
Food, beverage and tobacco	0.198	0.081	-0.082	0.091	-0.058	0.388
Furniture and related products	0.559	0.457	-0.16	0.407	-0.052	0.742
Machinery	0.7	0.309	-0.009	0.172	0.042	0.294
Mining	0.341	0.09	-0.12	0.361	0.484	0.207
Miscellaneous	1	0.321	-0.079	0.391	-0.034	0.553
Motor vehicles and parts	0.321	1	-0.231	0.244	0.055	0.534
Natural gas distribution	-0.079	-0.231	1	0.021	-0.003	-0.219
Non-metallic mineral product	0.391	0.244	0.021	1	0.299	0.312
Oil and gas extraction	-0.034	0.055	-0.003	0.299	1	0.062
Paper	0.553	0.534	-0.219	0.312	0.062	1
Petroleum and coal products	0.389	0.305	-0.253	0.449	0.415	0.383
Plastics and rubber products	0.535	0.567	-0.094	0.244	-0.001	0.734
Primary metal	0.693	0.482	-0.262	0.461	0.239	0.609
Printing and related support activities	0.404	0.232	-0.079	0.385	0.179	0.452
Textiles and products	0.49	0.47	-0.15	0.243	-0.039	0.808
Transportation equipment	0.245	0.836	-0.321	0.44	0.289	0.544
Wood product	0.581	0.41	-0.067	0.621	0.155	0.693

Table 8: Correlation Structure (Cont.)

	Petroleum and coal products	Plastics and rubber products	Primary metal	Printing and Related Support Activities	Textiles and products	Transportation Equipment	Wood product
Apparel and leather goods	0.121	0.323	0.368	0.423	0.52	0.22	0.214
Chemical	0.64	0.598	0.727	0.489	0.531	0.496	0.693
Computer and electronic product	0.18	0.308	0.207	0.411	0.216	0.07	0.265
Computers, communications equipment, and semiconductors	0.113	0.23	0.097	0.373	0.154	0.1	0.223
Crude processing	0.499	0.12	0.555	0.408	0.197	0.304	0.316
Electrical equipment, appliance, and component	0.539	0.628	0.652	0.597	0.522	0.522	0.678
Electric power generation, transmission, and distribution	-0.1	0.05	0.004	0.075	-0.154	0.057	-0.141
Fabricated metal product	0.56	0.56	0.731	0.59	0.498	0.486	0.572
Food, beverage and tobacco	0	0.217	0.161	0.255	0.423	0.003	0.262
Furniture and related products	0.509	0.655	0.495	0.457	0.804	0.379	0.716
Machinery	0.292	0.232	0.572	0.354	0.268	0.231	0.222
Mining	0.402	0.01	0.425	0.267	0.049	0.281	0.183
Miscellaneous	0.389	0.535	0.693	0.404	0.49	0.245	0.581
Motor vehicles and parts	0.305	0.567	0.482	0.232	0.47	0.836	0.41
Natural gas distribution	-0.253	-0.094	-0.262	-0.079	-0.15	-0.321	-0.067
Non-metallic mineral product	0.449	0.244	0.461	0.385	0.243	0.44	0.621
Oil and gas extraction	0.415	-0.001	0.239	0.179	-0.039	0.289	0.155
Paper	0.383	0.734	0.609	0.452	0.808	0.544	0.693
Petroleum and coal products	1	0.408	0.6	0.261	0.361	0.395	0.591
Plastics and rubber products	0.408	1	0.505	0.55	0.607	0.439	0.655
Primary metal	0.6	0.505	1	0.469	0.546	0.583	0.613
Printing and related support activities	0.261	0.55	0.469	1	0.439	0.29	0.397
Textiles and products	0.361	0.607	0.546	0.439	1	0.412	0.724
Transportation equipment	0.395	0.439	0.583	0.29	0.412	1	0.461
Wood product	0.591	0.655	0.613	0.397	0.724	0.461	1

7.4 Model parameters and calibration

Table 9 reports the model parameters. Columns 2 and 3 present the parameters used to produce the random draws from the sector-specific log-normal distribution of σ^j. The values are computed for σ as the annual standard deviation of the actual capacity utilization (computed for 47 years). The sector-specific empirical distributions of annual σ are, in general, best approximated by log-normal distributions. The first and second moments of these distributions (μ- and σ-Log-Normal) were calculated by means of Maximum-Likelihood estimation. The draws were further fitted to reflect the cross-correlations between industries, as reported in tables 5-8. The draws from multivariate log-normal distributions were generated with R-Studio and imported into our Netlogo simulations. The relative importance weights (RIW) of the various sectors appear in column 4. These are the mean values of the RIWs for each sector 1990-2007, taken from Setterfield (2019).

The values of c_σ^j are taken from table 2 (c_{thresh}). These were computed using the discrete threshold regression model discussed in section 3.2. The values for those sectors for which we could not find a threshold (*Electric power generation, transmission, and distribution*; *Food, beverage, and tobacco*; *Natural gas distribution* and *Oil and gas extraction*) were approximated by the average value of the filtered (5-MA) σ, 1972-2018. Even though the discrete threshold regression model could not detect a sectoral threshold for these industries, the remainder of our empirical analysis (section 3.1) suggests that the hysteresis mechanism is operative in these sectors, justifying our imputation of threshold values for these sectors. The values of χ^{Lj} and χ^{Uj} were calibrated so as to approximate the results of the threshold regression models with respect to $u_{n,H}$, $u_{n,L}$ and the threshold value c_σ^j (c_{thresh}) of the empirical data (table 2). The results are reported in table 3.

The parameter z denotes the number of periods required for a firm in any given sector to decide that volatility has decreased sufficiently to merit switching from u_{nL} to u_{nH} (see eq. 12). Specifically, each firm computes the average value of σ over the previous z periods ($\frac{1}{z}\sum_{l=1}^{z}\sigma_{t-l}^{i,j}$)

and switches to u_{nH} if the computed average falls below the critical value $c^{i,j}_{\sigma L}$. Similarly, m denotes the number of periods required for a firm in any given sector to decide that volatility has increased sufficiently to merit switching from u_{nH} to u_{nL} (see eq. 11). In this case, a firm that computes the average value of σ over the previous m periods ($\frac{1}{m}\sum_{l=1}^{m}\sigma^{i,j}_{t-l}$) will switch to u_{nL} if the computed average lies above the critical value $c^{i,j}_{\sigma H}$. The value of z was calculated by observing, in the data for each sector, the average number of periods required for the capacity utilization rate to switch from the lower to the upper normal rate regime in the event that σ changes from the high to the low volatility regime. A similar process was used to compute m.

Table 9: Calibrated parameters

Sector	μ **(log-normal dist.)**	σ **(log-normal dist.)**	μ_{RIW}	c^j_σ	χ^{Lj}	χ^{Uj}	z	m
Apparel and leather goods	0.344	0.517	0.0116	1.23	1.5	0.1	3	3
Chemical	-0.027	0.624	0.0824	1.24	0.6	0.6	3	3
Computer and electronic product	0.103	0.692	0.0735	2.01	0.1	1.2	5	3
Computers, communications equipment, and semiconductors	0.389	0.717	0.0498	2.57	0.1	1.5	3	3
Crude processing	0.108	0.627	0.094	1.65	0.1	0.6	8	4
Electrical equipment, appliance, and component	0.265	0.649	0.0187	1.45	0.6	1.2	0	2
Electric power generation, transmission, and distribution	0.446	0.291	0.0655	1.74	0.3	0.6	3	3
Fabricated metal product	0.032	0.669	0.045	2.16	0.3	1.8	11	0
Food, beverage and tobacco	-0.397	0.423	0.0842	0.81	0.3	0.6	3	3
Furniture and related products	0.336	0.573	0.0127	1.59	0.9	0.1	5	2
Machinery	0.528	0.548	0.0452	2.66	0.1	1.2	8	2
Mining	0.244	0.593	0.061	1.53	0.6	0.1	6	4
Miscellaneous	0.452	0.646	0.0229	1.12	1.2	0.3	3	0
Motor vehicles and parts	1.101	0.55	0.0508	4.31	0.6	1.8	3	2
Natural gas distribution	1.213	0.361	0.0105	3.64	1.8	1.5	3	1
Non-metallic mineral mining and quarrying	0.892	0.375	0.0174	3.13	0.1	1.2	6	3
Oil and gas extraction	-0.037	0.553	0.0393	1.08	1.8	0.9	5	3
Paper	0.214	0.555	0.0249	1.23	1.2	0.6	3	2
Petroleum and coal products	0.325	0.488	0.0164	1.87	0.1	0.6	10	4
Plastics and rubber products	0.328	0.679	0.028	1.36	1.8	0.1	4	2
Primary metal	0.877	0.58	0.022	3.52	0.1	1.8	4	6
Printing and related support activities	-0.098	0.501	0.0198	1.30	0.1	0.6	6	3
Textiles and products	0.356	0.624	0.012	1.82	0.9	1.2	3	3
Transportation equipment	0.635	0.601	0.0806	3.30	0.1	1.8	1	0
Wood product	0.507	0.613	0.0118	2.18	1.2	0.6	3	5

Source: Federal Reserve Bank of St. Louis (FRED) and the US, and own calculation.

7.5 Robustness check: discrete threshold regression model with time trend

In order to further examine the presence of hysteresis in the normal rate of utilization, we estimate the discrete threshold regression model using our filtered (5-MA) data, but *without* removing the linear trend. In other words, the data for the regressions that follow is filtered but not detrended. This revised discrete threshold regression model serves as a robustness check for the results reported in table 2, which are derived from estimates of a discrete threshold regression model using the filtered (5-MA) and detrended annual average rate of capacity utilization (i.e. u_n). The discrete threshold regression model estimated here involves two linear regressions with the same marginal effect in the time trend t but with two different intercepts, separated at a the threshold value of σ_{t-1} as shown in equations (18) and (19):

$$u_{nt} = C_1 + \beta * t + \epsilon_t \quad \text{if} \quad 0 < \sigma_{t-1} < \sigma_{thresh} \tag{18}$$

$$u_{nt} = C_2 + \beta * t + \epsilon_t \quad \text{if} \quad \sigma_{thresh} < \sigma_{t-1} < \infty \tag{19}$$

In this revised model, the normal capacity utilization rate is the dependent variable, the year (t) is the independent non-threshold variable and σ_{t-1} is the threshold variable.

Table 10 presents the results, which support those found in table 2. Table 2 shows that there exists a threshold value of σ_{t-1} in nearly every sector. Thus, the intercept value of u_n, the sectoral normal rate of capacity utilization, drops if the threshold value for the (lagged) value of σ is exceeded.

Table 10: Robustness check: discrete threshold regression model with non-detrended data

Sector	$\mathbf{C_1}$	$\mathbf{C_2}$	**Threshold** (σ_{thresh})	**Slope parameter (year, i.e.** t**)**	$\mathbf{R^2}$
Apparel and leather goods	696.68***(60.73)	691.54***(60.82)	1.23	−0.31***(0.03)	0.76
Chemical	589.63***(47.86)	585.60***(47.64)	1.24	−0.25***(0.02)	0.73
Computer and electronic product	590.10***(35.73)	583.71***(35.62)	2.01	−0.26***(0.02)	0.86
Computers, communications equipment, and semiconductors	283.94***(71.82)	278.14***(71.97)	2.57	−0.10**(0.04)	0.40
Crude processing	226.94***(32.09)	224.78***(32.07)	1.65	−0.07***(0.02)	0.45
Electrical equipment, appliance, and component	544.78***(81.02)	540.32***(80.58)	1.45	−0.23***(0.04)	0.43
Electric power generation, transmission, and distribution	365.21(92.01)	-	-	−0.14**(0.05)	0.16
Fabricated metal product	134.4·(77.98)	130.23(78.31)	1.97	−0.03(0.04)	0.13
Food, beverage and tobacco	415.17***(32.91)	-	-	−0.17***(0.02)	0.69
Furniture and related products	800.63***(105.76)	795.84***(104.92)	1.58	−0.36***(0.05)	0.50
Machinery	625.93***(89.05)	618.41***(88.61)	2.66	−0.27***(0.04)	0.50
Mining	234.22***(49.79)	231.69***(49.67)	1.53	−0.07**(0.02)	0.28
Miscellaneous	172.91***(36.36)	169.93***(36.11)	1.12	−0.048*(0.018)	0.45
Motor vehicles and parts	665.44***(106.56)	655.55***(106.23)	4.31	−0.29***(0.05)	0.57
Natural gas distribution	289.12***(79.63)	-	-	−0.10*(0.04)	0.12
Non-metallic mineral mining and quarrying	158.98***(44.73)	151.73**(44.79)	3.13	−0.04(0.02)	0.71
Oil and gas extraction	−48.41(42.26)	-	-	0.07**(0.02)	0.18
Paper	602.20***(36.04)	599.68***(35.83)	1.33	−0.26***(0.018)	0.82
Petroleum and coal products	136.13(91.36)	129.89(91.24)	1.87	−0.024(0.05)	0.30
Plastics and rubber products	781.88***(78.76)	773.91***(78.21)	1.79	−0.349***(0.04)	0.66
Primary metal	869.08***(148.47)	860.46***(147.37)	2.86	−0.39***(0.07)	0.39
Printing and related support activities	1161.18***(71.8)	1156.75***(71.68)	1.30	−0.54***(0.04)	0.84
Textiles and products	1090.29***(91.02)	1084.29***(90.49)	1.87	−0.51***(0.05)	0.73
Transportation equipment	186.83***(53.13)	179.15**(53.26)	3.30	−0.06*(0.03)	0.60
Wood product	934.05***(59.59)	924.49***(59.31)	2.18	−0.43***(0.03)	0.85

Source: Federal Reserve Bank of St. Louis (FRED) and the US, and own calculations.
Notes: Standard errors in parentheses; *** denotes significance at the 0.1% level; ** denotes significance at the 1% level; * denotes significance at the 5% level; · denotes significance at the 10% level.
Description: The Table shows the results for a threshold regression model, estimated via OLS. The data was trimmed by 15% for the regression. The normal rate of capacity utilization (u_n) is the dependent variable, the variable *year* (trend) is the independent variable to account for the time trend and σ_{t-1} is the threshold variable. The threshold is tested via the Bai-Perron test (Bai and Perron, 2003). The model tests whether a threshold value of σ_{t-1} exists such that the OLS regression between u_n and the variable *year* could be split into two regressions with the same slope but different intercepts. C_1 and C_2 are these intercepts, while the column 5 shows the slope parameter. For most of the sectors, intercept C_1 is above intercept C_2, which implies that the normal rate of capacity utilization is higher in case of σ_{t-1}-values below the threshold. For the sectors *Electric Power Generation, Transmission and Distribution*;*Food, beverage and tobacco*; *Natural gas distribution* and *Oil and gas extraction* we cannot find a threshold value. For the sector *Fabricated Metal*, we can only find significant results if the level of significance is extended to 0.1. The model was estimated with EViews 11.

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