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PHANTOM CYCLES

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Phantom cycles*

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Abstract: Phantom vacancies, or phantoms for short, are jobs that everyone can see but that none can get because they are already filled. Phantom cycles are deterministic fluctuations caused by the dynamics of phantoms and its interaction with vacancy supply. This paper argues that phantom cycles are more relevant for sclerotic labor markets (e.g., France) than for countries with high worker turnover (e.g., the US). We use our model of equilibrium search unemployment with phantom vacancies (Chï¿½ron and Decreuse, 2017). This model generates limit cycles associated to a Hopf bifurcation. We calibrate phantom cycles on aggregate data for 6 OECD countries. The expected duration of phantoms increases with the steady-state job-finding rate, reaching implausibly low values in the US where unemployment spells are notoriously short.

Keywords: Search and matching; Limit cycles; Obsolete information

1 Introduction

Phantom vacancies, or phantoms for short, are jobs that everyone can see but that none can get because they are already filled. Phantom cycles are deterministic fluctuations caused by the dynamics of phantoms and its interaction with vacancy supply. During phantom cycles, the vacancy-to-phantom ratio is procyclical and governs the matching efficiency, i.e., the total factor productivity of the matching technology that forms new jobs from unemployed and vacancies. The vacancy-to-phantom ratio increases during booms, which improves the matching efficiency and strengthens the decline in unemployment. However, phantoms accumulate, threatening the rise in the vacancy-to-phantom ratio. At the cycle reversal, phantoms outgrow vacancies, firms reduce job creation and unemployment increases.

This paper questions the relevance of phantom cycles for OECD countries. We use our model of equilibrium search unemployment where phantoms negatively impact the matching technology (Chï¿½ron and Decreuse, 2017). This model generates limit cycles in specific parametrizations. We calibrate such cycles on aggregate data for a selection of countries. The

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resulting phantom lifetime expectancy increases with worker turnover, reaching implausibly large values in the US where unemployment spells are very short. Phantom cycles, therefore, are more relevant for countries with sclerotic labor markets (e.g., France) than for countries with high worker turnover (e.g., the US).

Information obsolescence is a source of intertemporal matching frictions. Current match formation fuels the phantom stock, thereby reducing future matching efficiency. In our earlier contribution, we show that this single source of matching frictions generates an aggregate matching function with constant returns to scale (CRS) in the long run and increasing returns to scale (IRS) in the short run. A rise in the current number of available vacancies not only improves the number of job opportunities per job seeker, but also increases the vacancy-to-phantom ratio. Long-run CRS imply there is a unique steady state with standard comparative statics properties. Short-run IRS may lead to self-fulfilling prophecies and endogenous fluctuations. In particular, the model can predict the emergence of a limit cycle associated to a Hopf bifurcation.

Our model is composed of three differential equations (Section 2). The first one characterizes the dynamics of market tightness, i.e., the vacancy-to-unemployed ratio, induced by the free-entry condition. Changes in tightness (positively) respond to changes in matching efficiency. The second equation describes the dynamics of unemployment in terms of inflows and outflows. The last equation features the dynamics of the phantom stock. Phantoms increase with the flow of new jobs formed and depreciate at constant rate, the phantom death rate. In the standard model, the steady state is saddle-path stable: tightness jumps to its steady-state value and unemployment monotonically converges. Phantoms add a cyclical component induced by the pattern of phantom birth and death and its impact on matching efficiency. The steady state can be a sink or a source instead of a saddle and there may be a limit cycle associated to a Hopf bifurcation.

We focus on limit cycles and provide new theoretical results with respect to our earlier contribution. We insist on three properties linking phantom cycles to worker turnover and phantom lifetime. First, phantom cycles require that vacancies have short-run increasing returns in matching. In a Hopf bifurcation, the phantom-to-vacancy ratio must sufficiently respond to vacancies to leave the sink case. This implies the elasticity of the matching function with respect to vacancies is larger than one in the short run. Increasing returns to vacancies opens the room for self-fulfilling prophecies. If firms believe in a strong increase in matching efficiency, then they post many vacancies to benefit from larger job-filling rates. Therefore the phantom-to-vacancy ratio falls and this effect dominates the usual congestion externality. The job-filling rate actually increases thereby confirming the belief.

Second, the magnitude of increasing returns needed to reach the Hopf bifurcation tends to rise with worker turnover and decrease with phantom duration. Along the limit cycle, the repulsive force previously described must balance the attractive force due to phantom accumulation. Therefore the short-run elasticity with respect to vacancies increases with phantom inflow and decreases with phantom outflow in the Hopf bifurcation. High worker turnover implies a large flow of new jobs formed and, therefore, many new phantoms. Increasing returns to vacancies must be large to avoid the sink case where all trajectories end in steady state.

Third, the cycle period decreases with worker turnover and increases with phantom duration. Hopf bifurcation theory predicts the cycle period in the neighborhood of the bifurcation. This period increases with the persistence of the phantom-to-vacancy ratio. Therefore it decreases with the phantom death rate, which governs the phantom outflow, and the steady-state job finding rate, which affects the phantom inflow. Everything else equal, unemployment and vacancies should display lower persistence in high turnover countries than in low turnover ones along phantom cycles.

We then calibrate our model on monthly aggregate data for six OECD countries: France, Germany, Japan, Spain, the UK and the US (Section 3). Iin each calibration, the phantom birth rate to death rate ratio is set to one. Therefore, obsolete information persists for one month on average: by changing the phantom death rate, we modify the distribution of obsolete information by age but not its mean. In each country, we match the mean job-finding rate and the mean unemployment rate over three decades. For a given phantom death rate we find the short-run elasticity of the matching function leading to a Hopf bifurcation. Limit cycles obtain by slightly increasing this elasticity above the bifurcation value. We select the cycle that fits best the empirical volatility of unemployment. We then report the quarterly autocorrelation of unemployment and its correlation coefficient with tightness.

Phantom cycles are potential drivers of aggregate fluctuations in all countries but the US in our selection. Calibrated cycles display two main features in line with theory. On the one hand, the predicted auto-correlation of unemployment decreases with the phantom death rate in each country. Thus there is a fundamental trade-off between matching the strong persistence of unemployment and vacancies and keeping phantoms reasonably short-lived. On the other hand, the predicted auto-correlation of unemployment decreases with worker turnover. When the job-finding rate is large, phantom accumulation strongly responds to changes in market tightness and this reduces aggregate persistence accordingly. Therefore the phantom death rate must be set at a low value in countries with high worker turnover.

In France, Germany, Japan, Spain and the UK, worker turnover is low and phantoms do not need to last long to generate the empirically relevant level of aggregate persistence. Conversely, obsolete information needs to haunt the labor market for long in the US where the job-finding rate is very large. In our preferred calibrations, new jobs formed generate phantoms with probability one half and these phantoms last for two months on average. In France, Germany, Japan, Spain and the UK, the autocorrelation parameter lies between 0.69 and 0.84 against between 0.85 and 0.94 in the data. In the US, the autocorrelation parameter is -0.19 against 0.91 in the data. The parameter only increases to 0.5 when the phantom birth probability is set to 1/6 and phantoms last for 6 months on average.

1.1 Literature

This paper relates to three strands of literature: the burgeoning one on obsolete information in search markets, the well-advanced one on the propagation of exogenous shocks in equilibrium search models, and the renewed one on endogenous fluctuations with or without search frictions.

1.1.1 Obsolete information in the labor market

We first contribute to establishing obsolete information as a credible source of search frictions. We use a reduced-form aggregate matching function postulating the existence of obsolete information and abstracting from the precise mechanisms leading to it.

In our earlier contribution, we argue that phantoms are very widespread on the web and generate many testimonies of frustration. People feel betrayed and distrust digital platforms as a result. In a related context, Fradkin (2018) shows that this kind of frustration can discourage people from searching on Airbnb.

Phantoms exist because firms do not withdraw obsolete ads and digital platforms do not clean their website sufficiently fast. On the firms' side, deleting ads comes at some cost and generates very small gains. Moreover many ads are automatically republished on other websites thereby leaving the firms' control. Acharya and Wee (2018) also argue that some firms keep ads open in the hope of finding a better worker. The corresponding vacancies are not phantoms per se, but the probability of having them is lower than with unoccupied jobs because the new worker has to surpass the productivity of the hired one (likely augmented by an adjustment cost). In our paper, phantoms correspond to the case where the probability of having the job is quasi zero when it is already occupied.

Our matching function eludes the possibility for agents to mitigate the role played by information obsolescence. Job-seekers can see the listing age and adjust their search behavior accordingly. In this respect, Albrecht et al (2022) show that this behavior does not significantly reduce phantom formation and their impact on matching efficiency. The reason is that phantoms are tied to job creation. Using a better search technology generates more phantoms, which limits the technology impact on search outcomes.

Our numerical experiments illustrate well this idea. In the baseline calibration, we normalize market tightness to one in all countries. Therefore differences in the flow of new jobs formed come from underlying differences in the total factor productivity (TFP) of the matching function. It follows that the TFP parameter is very high in the US and this leads to a very large vacancy-to-phantom ratio. In the robustness section, we consider alternative parametrizations where market tightness differs across countries.

Phantoms as we describe them here are associated to internet. This is interesting in the context where internet expansion does not seem to affect the matching technology (see, e.g., Kroft and Pope, 2014, for evidence related to Craigslist). In their model with multiple applications, Albrecht et al (2006) explain this puzzling fact through the additional source of congestion due to having multiple firms competing for the same workers. Internet facilitates job contacts, but this may be detrimental to job formation. Obsolete information provides a complementary explanation whereby internet increases phantom exposure and survival[1].

1.1.2 Business cycles with exogenous shocks

Following Shimer (2005), researchers simulate the propagation of stochastic productivity shocks in equilibrium search models. However, market tightness is weakly correlated with productivity growth, especially since the mid 1980s (see, e.g., Hagedorn and Manovskii, 2011). Some papers consider alternative shocks as a result: see, e.g., Hagedorn and Manovskii (2011) who model stochastic home production and Eckstein et al (2019) who model shocks to the corporate interest rate. In our model, the cycle is driven by periodic changes in

[1] Martellini and Menzio (2019) have a different view. They argue that internet expansion and other improvements in the search technology lead to wage growth through increased workers' selectivity. This effect may fully offset the potential impacts on the job-finding rate at given vacancy-to-unemployed ratio.

matching efficiency, themselves induced by phantom dynamics. Therefore phantom cycles do not involve any correlation between unemployment and productivity.

We examine the relevance of phantom cycles for 6 OECD countries. In this respect, our study is similar to Amaral and Tasci (2016) who study the propagation of productivity shocks in a set of 13 OECD countries. Justiniano and Michelacci (2012) also focus on 6 OECD countries and model a broad set of shocks including shocks to the TFP of the matching function. Productivity shocks alone capture well the dynamics of the US labor market. However, and much in line with our results, matching shocks are needed to replicate the labor market dynamics in the other countries.

Our calibration methodology shares some features with the quoted papers. In particular, we set the bargaining power to a low value, typically 5%. This implies rigid wages during the cycle. In the standard model with random productivity shocks, sticky wages are needed to increase predicted unemployment volatility. In our model, unemployment volatility can easily be increased. However, we need sticky wages to increase predicted persistence. When wages are very responsive to tightness, the cycle reversal occurs very early and the cycle period is too short.

The main departure from usual calibrations is about the long-run elasticity of the matching function with respect to vacancies. There is no consensus on the value of this elasticity. It is accepted that it belongs to the unit interval (Petrongolo and Pissarides, 2001). Many papers fix it to 0.5 because this is the middle of the interval. Shimer (2005) chooses 0.35, the empirical elasticity of the job-finding probability with respect to tightness in the US. In our case we set it to one – slightly below one would work as well. Here again, we do so to improve the predicted persistence of phantom cycles. When the elasticity is small, the job-finding rate does not react much to changes in tightness. This forces us to increase the short-run elasticity of the matching function to reach the Hopf bifurcation. The period of the cycle falls and aggregate persistence is too low.

1.1.3 Limit cycles

Our paper contributes to the limit cycle view of aggregate fluctuations. Trade cycles have been popular from the 1960s to the early 1990s. Beaudry et al (2018) have recently called for a revival of this strand of research. They provide a model where demand complementarities originate a limit cycle, whereas the cycle is combined with technological disturbances that render fluctuations irregular. In their model, agents find advantageous to concentrate their purchases when unemployment is low. In our model firms concentrate vacancy postings in bad times to benefit from short-run increasing returns in matching. Then phantoms accumulate and deteriorate the matching efficiency, thereby leading to the cycle reversal. That today's success in search markets is a cause for tomorrow's failure provides a natural mechanism behind deterministic cycles.

The search and matching literature already emphasizes that *decreasing returns to scale* in matching may generate endogenous fluctuations (see, e.g., Ellison et al, 2014). Decreasing returns in matching are formally equivalent to having operating profits increasing in employment as in Mortensen (1999) and Kaplan and Menzio (2016). These models feature multiple steady states and there is a continuum of equilibrium trajectories leading to one of the steady states or even a limit cycle. Sniekers (2018) calibrates on US data the limit cycle of the Mortensen (1999) model where output per worker increases with employment. Sniekers names Beveridge cycles this type of cycles moving the unemployment rate and the vacancy rate around the Beveridge curve.

Phantoms imply CRS in the long run and, potentially, increasing returns to vacancies in the short run. The economic mechanism not only differs (information obsolescence vs productive externality), but also the mathematical concept behind the limit cycle. Sniekers studies a global bifurcation in the context of multiple steady states, whereas we examine a local one with a unique steady state (a Hopf bifurcation). The main message conveyed by both papers is that limit cycles can realistically occur in the context of developed economies with frictional labor markets.

2 Theory

This section presents our model with phantom vacancies (Chï¿½ron and Decreuse, 2017) and new results on its dynamic properties. We study the subspace of parameters leading to a Hopf bifurcation and discuss the period of the associated limit cycle.

2.1 The model

We present a textbook model of equilibrium search unemployment but the matching function. Therefore we briefly describe the standard assumptions and spend more time on the matching sector.

2.1.1 Standard assumptions

Time, t, is continuous and goes from 0 to infinity. The economy is populated by a continuum of workers whose total mass is one. They can be either unemployed, in mass u, or employed, in mass $1-u$. Firms offer vacant positions, v. Holding a vacancy costs c per unit of time. Employed workers produce $y=1$ and receive wage w. Unemployed workers receive b. Filled jobs can be destroyed at rate s. In such a case the worker joins the pool of unemployed. The wage results from the asymmetric Nash solution to the bargaining problem and $\gamma \in [0,1]$ denotes workers' bargaining power. All agents discount time at rate $r \geq 0$.

2.1.2 Matching sector

Unemployed and vacancies are brought together by pair via a matching function. Matches produce phantoms, p, that, in turn, deteriorate the efficiency of the matching function. The flow number of matches, M, is given by

$$M = \pi^{\lambda} A u^{1-\alpha} (v+p)^{\alpha}, \tag{1}$$

where $\pi \equiv v/(v+p)$ is the vacancy proportion, $A>0$, $\alpha \in [0,1]$ and $\lambda \geq \alpha$. The function has two components. The number of contacts, $Au^{1-\alpha}(v+p)^{\alpha}$, increases with unemployed, u, and seemingly available positions, $v+p$. The probability that contacts lead to actual matches, π^{λ}, increases with the vacancy proportion, π, in the overall supply of jobs. The number of matches can be rewritten as $M = A\pi^{\lambda-\alpha}u^{1-\alpha}v^{\alpha}$, which shows that phantoms impact the matching efficiency, $\kappa = A\pi^{\lambda-\alpha}$, of a standard Cobb-Douglas function. When $\lambda = \alpha$, $\kappa = A$ and phantoms do not affect matches. Otherwise, $\lambda > \alpha$ and $\partial M/\partial p < 0$ so that phantoms create a negative externality on the matching function.

The job-finding rate is $\mu = M/u = \kappa\theta^{\alpha}$. It increases with market tightness, $\theta = v/u$, and matching efficiency, κ. The job-filling rate, $\eta = M/v = \kappa\theta^{\alpha-1}$, decreases with tightness and increases with matching efficiency.

The phantom dynamics is

$$\dot{p} \equiv dp/dt = \beta M - \delta p, \tag{2}$$

where $\beta \geq 0$ is the phantom birth rate, $\delta \geq 0$ the phantom death rate and $p(0) = p_0$ the initial phantom stock. Matches give birth to phantoms at rate β. These phantoms die at Poisson rate, which implies that the expected phantom lifetime is $1/\delta$. The mean duration of obsolete information, therefore, is $\sigma \equiv \beta/\delta$.

The short-run elasticity with respect to vacancies is

$$\varepsilon_v^{SR} \equiv d\ln M/d\ln v = \alpha + (\lambda - \alpha)(1 - \pi). \tag{3}$$

An increase in vacancies raises the number of contacts, which is accounted for by the elasticity α, but also reduces the share of phantoms in the overall supply of positions, which is captured by the term $(\lambda-\alpha)(1-\pi)$. This term increases with parameter λ and the phantom proportion $1 - \pi$. The short-run elasticity, therefore, is larger at times where the vacancy-to-phantom ratio is small. The short-run elasticity may be larger than one. In such a case the usual congestion externality is dominated by the decline in phantom proportion and the job-filling rate, η, increases with the number of vacancies.

In the long run, matches fuel the phantom stock, thereby reducing the matching efficiency. Accounting for this effect reduces the vacancy impact on the matching technology. In steady state, u and v are constant and the stationary number of phantoms is $p = \sigma M$. The stationary flow of matches is

$$M = A\left(\frac{v}{v + \sigma M}\right)^{\lambda-\alpha} u^{1-\alpha}v^{\alpha}.$$

This equation implicitly defines the long-run matching function $M = m^{LR}(u, v)$. The function m^{LR} has the properties of a standard matching technology. It is strictly increasing in its arguments, strictly concave, satisfies $m^{LR}(0, v) = m^{LR}(u, 0) = 0$ and $\lim_{v\to\infty} m^{LR}(u, v) = \lim_{u\to\infty} m^{LR}(u, v) = \infty$. Its elasticities with respect to u and v are

$$\varepsilon_u^{LR} \equiv \frac{d\ln M}{d\ln u} = \frac{1-\alpha}{1-\alpha+\bar{\varepsilon}_v^{SR}}, \tag{4}$$

$$\varepsilon_v^{LR} \equiv \frac{d\ln M}{d\ln v} = \frac{\bar{\varepsilon}_v^{SR}}{1-\alpha+\bar{\varepsilon}_v^{SR}} = 1 - \varepsilon_u^{LR}, \tag{5}$$

where $\bar{\varepsilon}_v^{SR}$ is the short-run elasticity of the matching technology evaluated in stationary state.

Thus the long-run matching function has constant returns to scale. Note that $\varepsilon_v^{LR} > \alpha$ and $\varepsilon_u^{LR} < 1 - \alpha$ when $\lambda > \alpha$ and $\alpha < 1$. This is so because of the additional effect of vacancies on the stationary vacancy proportion.

2.1.3 Equilibrium

The interested reader will find the derivation of the model in our previous paper, Chï¿½ron and Decreuse (2017). It is composed of three differential equations linking market tightness, unemployment and phantoms:

$$(1-\alpha)\frac{\dot{\theta}}{\theta}-\frac{\dot{\kappa}}{\kappa} = r+s-(1-\gamma)c^{-1}(y-b)\kappa\theta^{\alpha-1}+\gamma\kappa\theta^{\alpha}, \quad (6)$$

$$\dot{u} = s(1-u)-\kappa\theta^{\alpha}u, \quad (7)$$

$$\dot{p} = \beta\kappa\theta^{\alpha}u-\delta p, \quad (8)$$

with $\kappa = A[\theta u/(\theta u+p)]^{\lambda-\alpha}$, $u(0)=u_0$ and $p(0)=p_0$ given.

The main originality of the free-entry condition (FE) is that the percentage change in tightness, $\dot{\theta}/\theta$, positively responds to the (endogenous) percentage change in matching efficiency, $\dot{\kappa}/\kappa$. The Beveridge curve (BC) gives the change in unemployment as the difference between inflows, $s(1-u)$, and outflows, $\kappa\theta^{\alpha}u$. In the phantom accumulation equation (PA), the inflow of new phantoms is the proportion β of the outflow from unemployment.

We rewrite the dynamic system in a more convenient way. Let $x = p+\beta u$. We have

$$(1-\alpha)\frac{\dot{\theta}}{\theta} = \frac{\dot{\kappa}}{\kappa}+r+s-(1-\gamma)\frac{y-b}{c}\kappa\theta^{\alpha-1}+\gamma\kappa\theta^{\alpha}, \quad (9)$$

$$\dot{u} = s(1-u)-\kappa\theta^{\alpha}u, \quad (10)$$

$$\dot{x} = \beta s+\beta(\delta-s)u-\delta x, \quad (11)$$

with $\kappa = A\pi^{\lambda-\alpha}$, $\pi = \theta u/(\theta u+x-\beta u)$.

2.2 Hopf bifurcation

Owing to long-run constant returns to scale, the model has a unique steady state solving

$$r+s = (1-\gamma)\frac{y-b}{c}m^{LR}(1,\theta^*)/\theta^*-\gamma m^{LR}(1,\theta^*), \quad (12)$$

$$u^* = \frac{s}{s+m^{LR}(1,\theta^*)}, \quad (13)$$

$$x^* = \sigma s+\sigma(\delta-s)u^*. \quad (14)$$

In practice, we calibrate our model on aggregate data. Therefore the mean steady-state job-finding rate and market tightness must be model outcomes. Suppose $\mu>0$ and $\theta>0$ are given. From equation (12), we can deduce c so that $\theta^*=\theta$. From the definition of the job-finding rate $\mu=\kappa\theta^{\alpha}$, we can also find A so that $\mu^*=\mu$. This gives

$$A = \mu\theta^{-\alpha}(1+\sigma\mu/\theta)^{\lambda-\alpha}, \quad (15)$$

$$c = \frac{(1-\gamma)(y-b)\mu/\theta}{r+s+\gamma\mu}. \quad (16)$$

These parameters do not affect the stability properties of the steady state for given μ and θ. Hereafter, the steady state is normalized, which means that μ and θ are held fixed. Therefore A and c adjust in response to changes in other structural parameters of the model.

There are two predetermined variables, u and x, and one forward variable, θ. We are interested in parametrizations where there is a Hopf bifurcation leading to limit cycles. The bifurcation parameter is the short-run elasticity of the matching technology with respect to vacancy, ε_{LR}^{v}, simply denoted by ε. Let J denote the Jacobian matrix of system (9)-(11) evaluated in steady state. A Hopf bifurcation occurs when J admits one real negative eigenvalue, whereas the two others are conjugate complex with zero real part.

The following result supposes that there is a Hopf bifurcation when $\varepsilon = \varepsilon^H$.

Proposition 1 (Hopf bifurcation) *Let* $D = \det J$, $T = Tr(J)$, $Z = Tr(J^2)$. *The following properties hold:*

(i) Bifurcation algorithm: ε^H *solves* $T^2 - 2D/T = Z$ *and* $T < 0$

(ii) Bifurcation and increasing returns in the short run: $\varepsilon^H > 1$.

Proof. See the Appendix.

Property (i) describes the algorithm to compute the Hopf bifurcation value, ε^H, at given parameter set. This consists in solving $T^2 - 2D/T = Z$ in ε while checking that $T < 0$. Then the real part of the two complex eigenvalues becomes positive from negative and the steady state turns source from sink. In the bifurcation point and slightly above it, a limit cycle occurs. The analytical expressions of D, T and Z are given in the Appendix. The algorithm does not always return a value as a Hopf bifurcation does not exist for all parametrizations.

Property (ii) shows that the matching function must display increasing returns to vacancies in the short run. Phantom cycles are based on two opposite forces. First, a repulsive force pushes the dynamic system out of steady state and initiates the cycle. This force involves short-run increasing returns to vacancies. This implies that the job-filling rate, $\eta = M/v$, can temporarily increase with vacancies. Second, phantom accumulation drives the cycle reversal. Match formation progressively fuels the phantom stock, thereby reducing the matching efficiency. In the Hopf bifurcation, these forces balance each other and there is a limit cycle.

Proposition 1 generalizes our earlier result (see our Proposition 5) where we only focus on the case $\delta = s$. Then the expected phantom lifetime is equal to the expected job duration, which forbids us to discuss empirically credible cases. For instance, s is notoriously high in the US, about 2.5% in monthly unit of time. Still, this gives an average job duration of 40 months. Phantoms cannot last three years and still impact workers' search.

We now examine the magnitude of increasing returns to scale (IRS) involved in the Hopf bifurcation. We highlight the roles of the phantom death rate and worker turnover. A substantial literature in macrodynamics insists on the idea that large IRS are not very attractive because there is not much evidence in their favor (see, e.g., Wen, 1998, Benhabib and Wen, 2004). Here the problem differs because IRS are only needed in the short run, whereas the matching function displays constant returns in the long run. However, intuition suggests episodes where the job-filling rate increases with tightness should be kept short.

Proposition 2 (Magnitude of increasing returns to scale) *Let* ε^H *be the value of the bifurcation parameter in the Hopf bifurcation. The following properties hold:*

(i) ε^H tends to decrease with the phantom death rate:

$$\lim_{\substack{\delta\to 0\\ \beta/\delta=\sigma}} \varepsilon^H = \frac{((1-\alpha)\mu+s)(\gamma\mu+r+s)}{s(r+s)-\gamma\mu^2} > 1 \text{ and } \lim_{\substack{\delta\to \infty\\ \beta/\delta=\sigma}} \varepsilon^H = 1.$$

(ii) ε^H tends to increase with worker turnover:

$$\lim_{\substack{\mu\to 0\\ s/(\mu+s)=u}} \varepsilon^H = 1 \text{ and } \lim_{\substack{\mu\to \infty\\ s/(\mu+s)=u}} \varepsilon^H = \infty.$$

Proof: See the Appendix.

We only provide results for limit configurations where the parameter of interest tends to 0 or infinity. However, the main message is sufficiently acute to understand the numerical results exposed in the next section. The magnitude of IRS needed to obtain a Hopf bifurcation tends to decrease with the phantom death rate and increase with worker turnover. Information obsolescence is a credible source of deterministic fluctuations provided that the phantom death rate is sufficiently large and worker turnover is sufficiently low.

The impact of the phantom death rate is established at given expected duration of obsolete information, $\sigma = \beta/\delta$ (property (i)). Small (large) phantom death rates, δ, are compensated by small (large) phantom birth rates, β. Therefore by changing δ we modify the distribution of obsolete information duration without changing its mean. Similarly, the impact of the job-finding rate is established at given unemployment rate, $u = s/(s+\mu)$ (property (ii)). Small (large) job-finding rates are compensated by small (large) job loss rates. This is why we refer to the effects of worker turnover. This corresponds well to the usual distinction between sclerotic labor markets where worker turnover is low and flexible ones where it is high.

IRS are associated with the repulsive force that initiates the cycle. This force must balance the attractive force linked to phantom accumulation. When δ is high, β is high as well. Therefore both the phantom inflow and outflow are large and the impact on phantom accumulation is ambiguous. Computation reveals that phantom death tends to dominate phantom birth so that the attractive force gets smaller with δ. Therefore the magnitude of IRS needed to compensate it also tends to decrease with δ. When the job-finding rate is large, there are many new jobs formed at each instant. Thus the phantom inflow, $\beta M = \beta\mu u$, is massive and phantoms accumulate at a high pace. The repulsive force needs to balance this effect and this is why ε^H tends to increase with μ.

We now turn to another characteristic of phantom cycles, their duration and corresponding ability to reproduce the strong persistence of aggregate labor market data. The length of phantom cycles can be predicted by Hopf bifurcation theory. As ε increases above ε^H, the amplitude and period of the cycle increase. In the neighborhood of the bifurcation point, the period is $2\pi\sqrt{T/D}$, where $\pi = 3.14...$ is here the transcendental number. We explore the properties of the cycle period with respect to the job-finding rate, μ, and the phantom death rate, δ.

The following result assumes that a Hopf bifurcation exists.

Proposition 3 (Determinants of the cycle period) *Let P denote the limit cycle period in the neighborhood of the Hopf bifurcation. The following properties hold:*

(i) P tends to decrease with the phantom death rate:

$$\lim_{\substack{\delta \to 0 \\ \beta/\delta=\sigma}} P = \infty \text{ and } \lim_{\substack{\delta \to \infty \\ \beta/\delta=\sigma}} P = 0.$$

(ii) P tends to decrease with worker turnover:

$$\lim_{\substack{\mu \to 0 \\ s/(s+\mu)=u}} P = 2\pi\sqrt{-\frac{r}{2\delta^3} + \frac{2}{\delta r((1+8(\delta/r)^2)^{1/2}-1)}} \text{ and } \lim_{\substack{\mu \to \infty \\ s/(s+\mu)=u}} P = 0.$$

Proof. See the Appendix.

Here again, we only provide results for extreme configurations. The phantom death rate and worker turnover play against the duration of phantom cycles. Therefore phantom cycles feature low persistence when obsolete information does not last and unemployment spells are very short.

The cycle period is deeply influenced by the persistence of the vacancy proportion. In turn, such persistence is impacted by the phantom death rate and job-finding rate. Both parameters increase the phantom inflows – job-finding rate – and outflows – phantom death rate –, thereby increasing the sensitivity of the phantom stock to short-term shocks.

Flexible labor markets with high worker turnover are associated with short phantom cycles and large IRS in matching in the short run. To increase the cycle duration, we have to decrease phantom death rates. This further increases the magnitude of IRS needed in the Hopf bifurcation. Moreover these death rates can become unrealistically small.

In the next section, we calibrate phantom cycles for six OECD countries and show that the resulting phantom death rates are too low in the US, whereas they remain reasonably large in the other countries.

3 Quantitative investigations

We calibrate phantom cycles for six OECD countries. We first present the data and the methodology. Then we show the results and discuss their robustness. We emphasize the role played by the phantom death rate and the job-finding rate.

3.1 Calibrations

3.1.1 Data

We exploit aggregate data from Barnichon and Garda (2016) to proxy steady-state values for the job-finding rates, μ, and the job loss rate, s. They focus on six OECD countries: France, Germany, Japan, Spain, the UK and the US. They construct workerflow series from data on the stocks of unemployment and short-term unemployment following Shimer (2012) and Elsby et al (2013). Then they compute the corresponding monthly inflow and outflow rates at quarterly frequency for the period 1977:1-2011-4. For each country, we assimilate the steady-state job-finding and job loss rates to their empirical mean over the available period.

As for unemployment and vacancies, we use OECD data as Amaral and Tasci (2016) for the six countries. We hp-filter the series with default smoothing parameter of $1,600$. We then compute the quarterly volatility and autocorrelation of unemployment and vacancies over the period 1977:1-2011-4. We here assume that the vacancy series only contain available vacancies, v, and are not contaminated by phantoms, p. In section 3.5, we consider the alternative case where these series actually describe $v + p$.

The panel of Figures 1 describes the data. The left-hand chart displays monthly inflow and outflow rates for the six countries. It shows the US specificity, where these rates are way higher than in the other countries. The US job-finding rate is 0.55, which implies that the mean unemployment duration is below two months. By contrast, the French job-finding rate is about 0.08 and the corresponding mean unemployment duration is one year. Theory predicts that phantom cycles will be hard to calibrate for the US, implying very large increasing returns to vacancies in the short run (Proposition 2) and very long-lived phantoms (Proposition 3).

The right-hand chart depicts unemployment persistence and volatility, i.e., the standard deviation and the autocorrelation parameter of the filtered series. There is more heterogeneity between countries than in the case of transition rates. Unemployment volatility ranges from 0.05 in France to 0.11 in the US. Persistence is large everywhere with autocorrelation parameters above 0.9, except in Japan where the autocorrelation parameter is about 0.85.

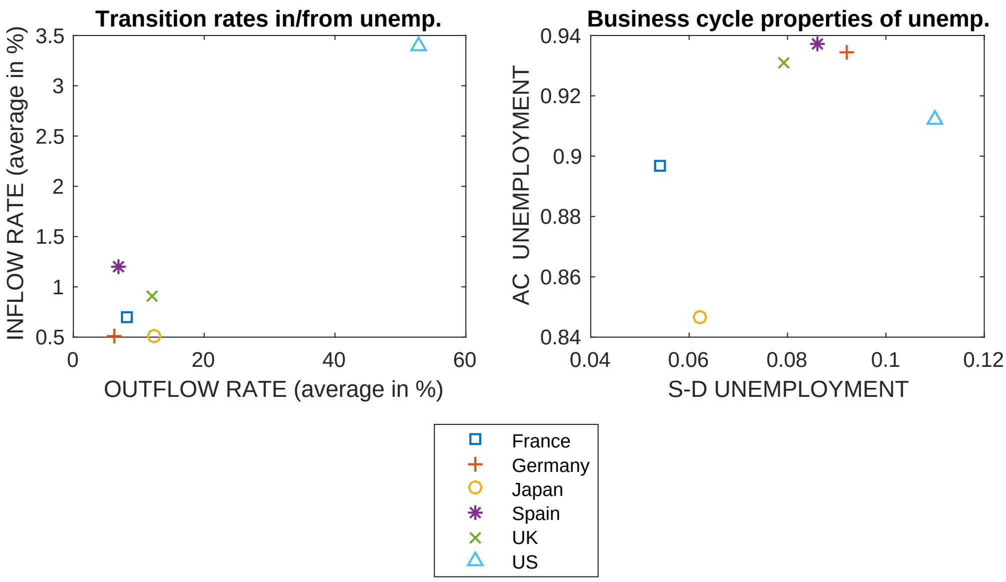
3.1.2 Strategy

To calibrate phantom cycles, we proceed as follows. We fix all parameters but three for each country. These three parameters are the phantom birth rate, β, the phantom death rate, δ, and the short-run elasticity of the matching function with respect to vacancies, ε. We let β and δ vary and find the bifurcation value ε^H in each parametrization. We increase ε above ε^H until the limit cycle displays the same unemployment volatility as in the data. We then report the covariance matrix between unemployment, vacancies and tightness as well as the autocorrelation parameter of these variables at quarterly frequency.

Parameters β and δ are not allowed to vary independently. Following Propositions 2 and 3, we fix the ratio of the phantom birth rate to the phantom death rate, $\sigma = \beta/\delta$, to a reasonable value. Therefore the expected duration of obsolete information does not change across parametrization. In practice, we choose $\sigma = 1$. This means that the phantom birth rate is equal to the phantom death rate and obsolete information lasts one month on average. Then we pick values for β and δ in the set $\{1/12, 1/6, 1/3, 1/2, 1\}$. Values below $1/2$ are too low, because they imply that phantoms last more than two months. We report the results with such low values to emphasize the difficulty faced by phantom cycles to match US unemployment persistence.

We then fix a subset of parameters to equal values in each country. We normalize output per worker to $y = 1$ and set the discount rate to $r = 0.3\%$. We then fix unemployment income to $b = 0.7$. We choose the same value for the six countries despite they have heterogenous unemployment compensation systems. However, b also encompasses the value of leisure and

Figure 1: Some stylized facts of unemployment



we have little clue about its cross-country heterogeneity.

We set two parameters to less conventional values. On the one hand, the elasticity of the contact rate with respect to vacancies is $\alpha = 1$. This implies that the long-run elasticity of the matching function is $\varepsilon_v^{LR} = 1$. If our model generated actual unemployment data and vacancy data, regressing the log job-finding rate on a constant and log tightness, i.e., $\ln \mu_t = a_0 + a_1 \ln \theta$, would give $\hat{a}_1 = 1$. As discussed in Introduction, this estimate lies in the upper part of accepted values. Similar quantitative results can be reached with an elasticity slightly below one.

On the other hand, though workers' bargaining power varies between 0.05 and 0.5 in our numerical simulations, our preferred value is $\gamma = 0.05$. The wage is $w = \gamma y + (1-\gamma)b + \gamma c\theta$. Choosing γ small means that the wage is very rigid during the business cycle. This assumption can be disputed, but the state of empirical research on the subject cannot reject it. Sticky wages have already been considered by Hall (2005) and Hagedorn and Manovskii (2008) to solve the unemployment volatility puzzle in the model with stochastic productivity shocks.

These choices, $\alpha = 1$ and $\gamma = 0.05$, are made on the basis of the model ability to reproduce unemployment persistence. When α is small, tightness does not respond much to changes in matching efficiency. The bifurcation parameter ε^H is large as a result and the vacancy proportion lacks persistence. Similarly, when γ is large, the wage absorbs most of the changes in matching efficiency. Tightness does not fluctuate enough unless the elasticity ε^H is very large again. These points will be made clear in the upcoming subsection. Note that we cannot have $\gamma = 0$. Otherwise, the trace, T, as shown in the Appendix, becomes positive. Proposition 1 shows we cannot obtain limit cycles in this case.

We follow Amaral and Tasci (2016) and normalize $\theta^* = 1$ in the absence of accurate information on the actual number of vacancies in each country. Modifying θ^* does not impact the qualitative properties of the dynamic system in the neighborhood of the steady state. In particular, it neither affects the parameter subset compatible with a Hopf bifurcation nor the period of the cycle in the neighborhood of the bifurcation. However, it implies that the stationary phantom-to-vacancy ratio increases with the job-finding rate. We discuss this property and consider an alternative calibration choice in section 3.5.

The remaining parameters take country-specific values. The unemployment inflow and outflow rates, respectively s and μ, are fixed to their mean values for each country. Parameters A and c adjust according to equations (15) and (16). As explained in Section 2, these values imply that μ and $\theta^* = 1$ are steady-state outcomes of the model. The final parameter, λ, determines the elasticity ε. Therefore it is the actual bifurcation parameter behind Hopf bifurcations and associated limit cycles. Its choice will be explained in the next two sections.

Table 1 reports the parameters in our preferred calibration, hereafter the benchmark calibration. It shows the US specificity where the scale parameter of the matching function, A, is four to seven times larger than in the other countries. This is implied by the calibration strategy so as to match the very large US job-finding rate. We focus on an alternative calibration strategy in the robustness subsection.

Table 1: Benchmark calibration: parameters

	r	y	b	α	δ	β	γ
	0.3%	1	0.7	1	0.5	0.5	0.05
	s	c	A	λ	ε		
France	0.007	1.66	0.09	1.66	1.05		
Germany	0.005	1.57	0.06	1.85	1.05		
Japan	0.005	2.48	0.13	1.51	1.06		
Spain	0.012	1.05	0.07	1.73	1.05		
UK	0.009	1.89	0.13	1.52	1.05		
US	0.034	2.37	0.59	1.27	1.09		

Table 2 displays the steady-state magnitude and impact of obsolete information. Phantoms only account for between 6 and 11% of the total vacancy stock in 5 of the 6 countries. This proportion reaches 35% in the US. This result is due to the normalization assumption $\theta^* = 1$, a statement discussed in the robustness section. Overall, phantoms do not account much in the magnitude of unemployment. Eliminating them by putting $\pi^* = 1$ leads to a reduction in unemployment by 0.5 percentage point on average.

Table 2: Benchmark calibrations: phantoms in steady state

	p^*/v^*	π^*	$A(\pi^*)^\lambda$	u^*	$u^*(\pi^* = 1)$
France	0.08	0.92	0.08	0.079	0.075
Germany	0.06	0.94	0.06	0.076	0.072
Japan	0.12	0.89	0.12	0.039	0.037
Spain	0.07	0.94	0.07	0.150	0.144
UK	0.12	0.89	0.12	0.070	0.067
US	0.53	0.65	0.53	0.060	0.054

3.2 Hopf bifurcation values

The first step towards the calibration of phantom cycles consists in focusing on Hopf bifurcations. We examine the Hopf bifurcation value of parameter ε, that we denote ε^H, for the different countries as a function of the job-finding rate, μ, the phantom death rate, δ, and workers' bargaining power, γ. Figure 2 shows the role of the job-finding rate and the phantom death rate for different values of the bargaining power. It highlights our preferred case where $\gamma = 0.05$.

As featured by Proposition 1, the elasticity ε^H is larger than one in all cases. The magnitude of IRS increases with workers' bargaining power. It is below 20% in all cases when $\gamma = 0.05$ and larger than 50% when $\gamma = 0.5$. When workers have a high bargaining power changes in matching efficiency are absorbed by changes in wages and do not impact tightness much. The elasticity ε^H must be large to compensate for this effect.

As suggested by Proposition 2, the elasticity ε^H decreases with the phantom death rate (property (i)) and increases with the job-finding rate (property (ii)). When the phantom

Figure 2: Hopf bifurcation value of the short-run elasticity ϵ as a function of the phantom death rate, job-finding rate and workers' bargaining power

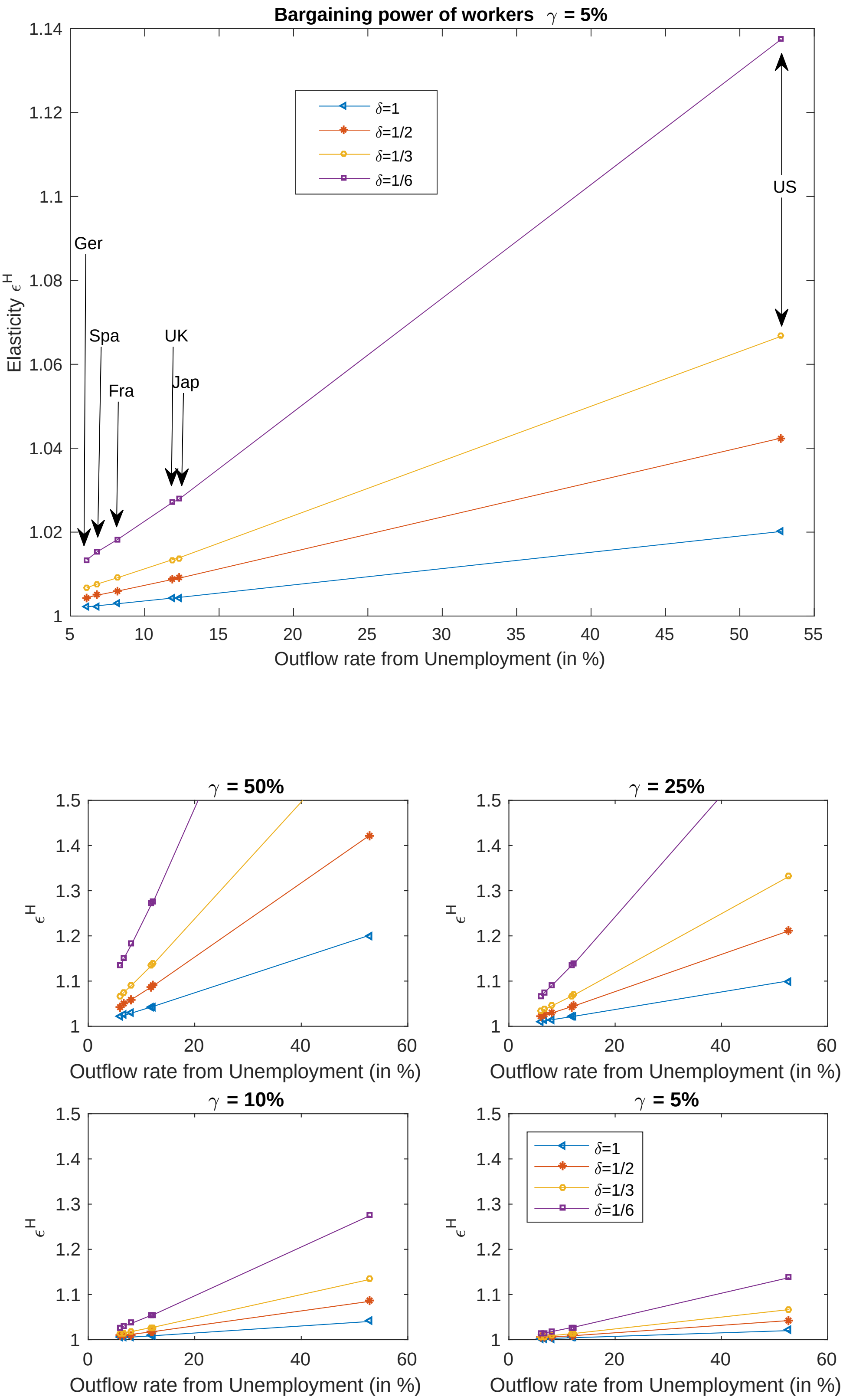
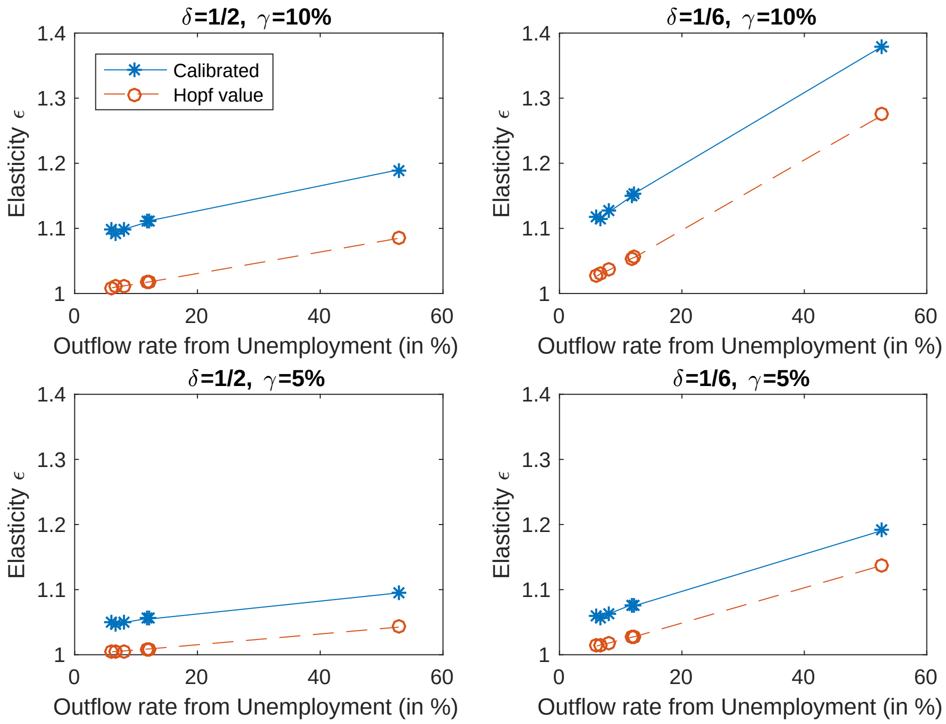


Figure 3: Hopf bifurcation vs calibrated values of the short-run elasticity ϵ



death rate is large, phantoms do not last long and the vacancy proportion is strongly procyclical. The elasticity ε^H is reduced accordingly. Since $\mu = \eta\theta^* = \eta$, large job-finding rates imply large job-filling rates. Therefore the inflow of new phantoms increases with the job-finding rate, which tends to reduce the procyclicality of the matching efficiency and its positive impact on job creation. The elasticity ε^H needs to increase in order to compensate for this effect.

Figure 2 points out the US specificity. The elasticity ε^H is much larger there than in the other countries at given phantom death rate. When $\gamma = 0.05$, IRS are below 1% for five out of the six countries when $\delta = 1/2$. They do not exceed 3% in the worst case where $\delta = 1/6$. In the US they are about 4% when $\delta = 1/2$ and reach 14% when $\delta = 1/6$.

To find phantom cycles we progressively increase ε above ε^H. Limit cycles appear and their amplitude grows with ε. We stop when unemployment volatility matches the empirical volatility displayed by the panel of Figures 1. Figure 3 shows the difference between the bifurcation value ε^H and the value of ε that we finally choose for the different countries. It does so for two values of δ, 1/6 and 1/2, and two values of γ, 5% and 10%. The difference between the two elasticities is 5 percentage points when $\gamma = 0.05$ and 10 percentage points when $\gamma = 0.1$.

3.3 Benchmark simulations of phantom cycles

We simulate the nonlinear model over 100,000 months and keep the 10,000 last observations to ensure that the model has converged to its limit cycle. We then compute logs of average quarterly values of unemployment and hp-filter them with smoothing parameter of $1,600$. The different statistics that we report are based on such filtered series.

The panel of Figures 4-5 shows the phantom cycles for the six countries in the benchmark calibration where $\gamma = 0.05$ and $\delta = 1/2$. Each cycle is first depicted in the (θ, u) plane. They describe an elliptic curve which main axis is downward sloping. Therefore unemployment and tightness are negatively correlated on average, like the Beveridge curve. Then we see the regular fluctuations of tightness and unemployment against calendar time.

Table 3 reports the related statistics of the business cycle for this benchmark case.

Table 3: Business-cycle properties of unemployment, vacancies and tightness: data vs phantom cycles

Figure 4: Tightness and unemployment during phantom cycles ($\gamma = 5\%$)

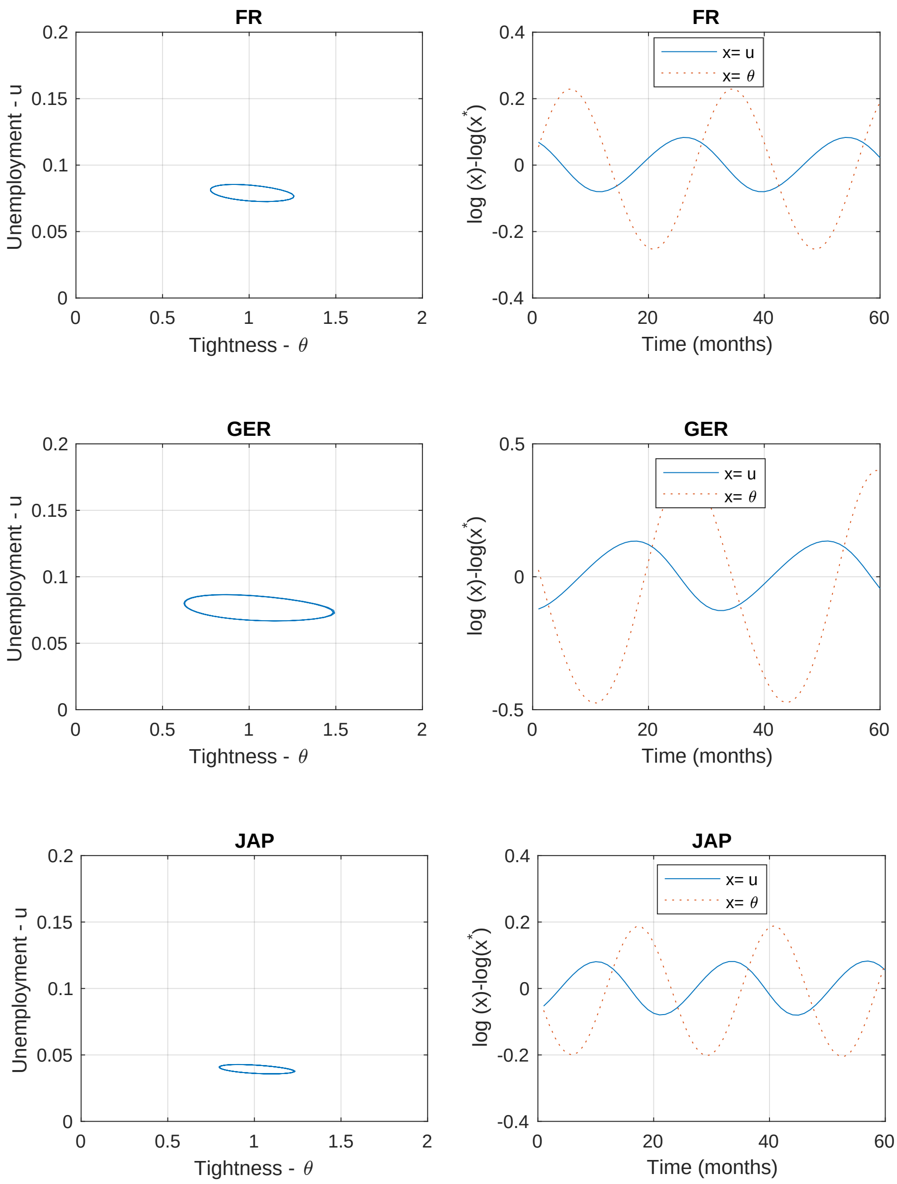
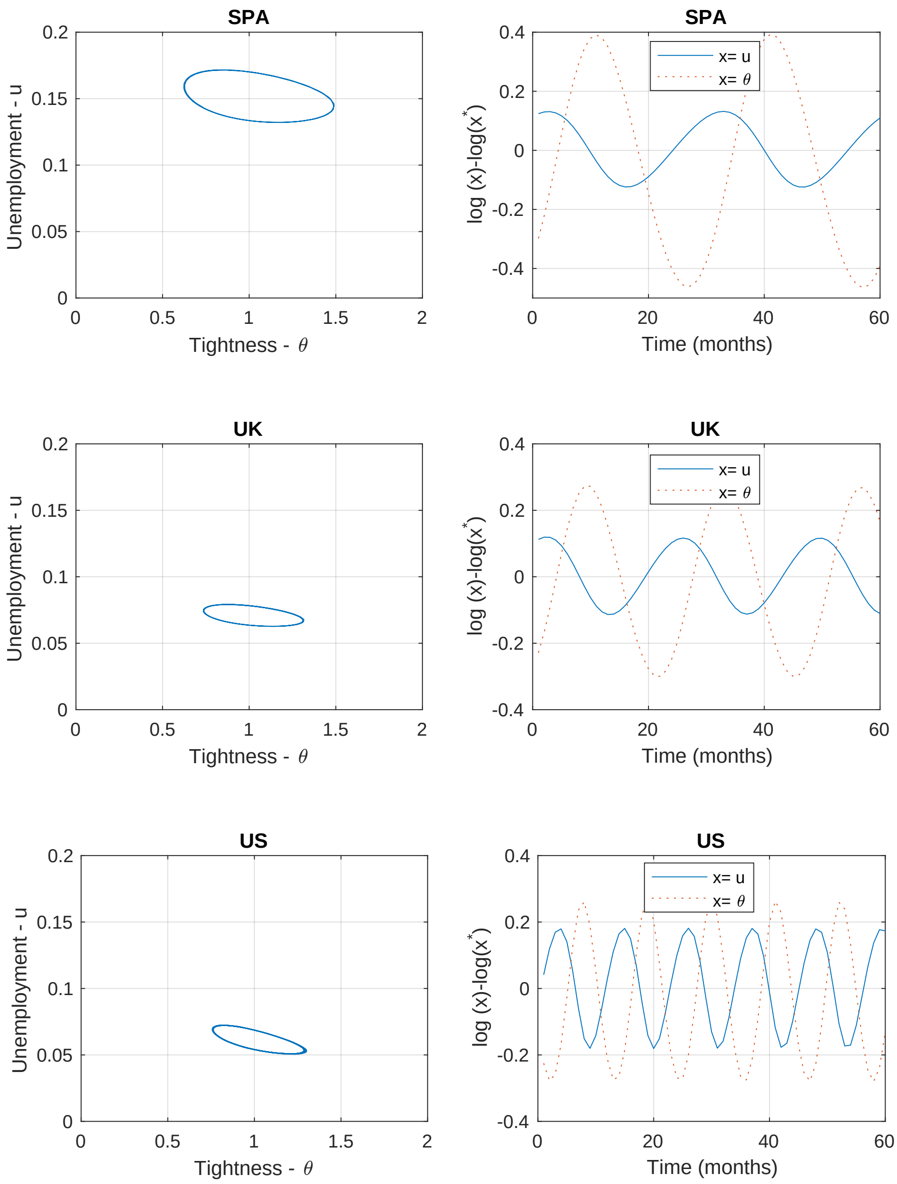


Figure 5: Tightness and unemployment during phantom cycles ($\gamma = 5\%$)



		$\sigma(u)$	$\sigma(v)$	$\sigma(\theta)$	$ac(u)$	$ac(v)$	$ac(\theta)$	$cor(u,v)$	$cor(u,\theta)$
France									
	Data	0.06	0.07	0.10	0.90	0.81	0.90	-0.30	-0.77
	Model	0.06	0.15	0.17	0.78	0.78	0.78	-0.04	-0.38
Germany									
	Data	0.09	0.18	0.26	0.93	0.95	0.95	-0.84	-0.93
	Model	0.09	0.28	0.30	0.84	0.84	0.84	-0.05	-0.34
Japan									
	Data	0.06	0.11	0.16	0.85	0.92	0.91	-0.82	-0.92
	Model	0.06	0.13	0.15	0.69	0.69	0.69	-0.04	-0.45
Spain									
	Data	0.09	0.15	0.18	0.94	0.79	0.83	-0.34	-0.59
	Model	0.09	0.28	0.30	0.81	0.81	0.81	-0.08	-0.37
UK									
	Data	0.08	0.15	0.21	0.93	0.91	0.92	-0.67	-0.85
	Model	0.08	0.18	0.20	0.70	0.70	0.70	-0.05	-0.45
US									
	Data	0.11	0.13	0.23	0.91	0.90	0.91	-0.92	-0.98
	Model	0.11	0.12	0.17	-0.12	-0.12	-0.12	-0.10	-0.73

Notes: This table reports the quarterly standard deviations of unemployment, vacancies and labor tightness, $\sigma(u)$, $\sigma(v), \sigma(\theta)$, their quarterly autocorrelation parameters, $ac(u)$, $ac(v)$, $ac(\theta)$, the contemporaneous correlation coefficients of unemployment with vacancies and tightness, $cor(u,v), cor(u,\theta)$, in the data and during the calibrated limit cycles for the six countries. The calibration procedure is explained in the body text. We set $\delta = 1/2$ and $\gamma = 0.05$. In both cases, unemployment is hp-filtered with parameter $\lambda = 1,600$.

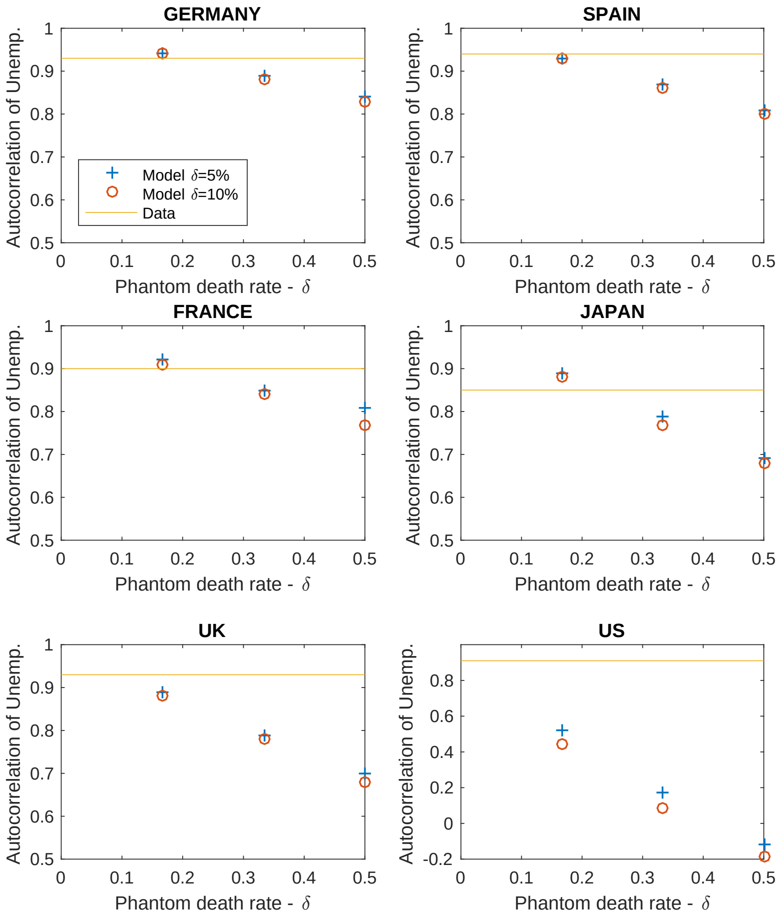
Table 3 gives the predicted and empirical covariance matrices of unemployment and vacancies for each country. Unemployment volatility, $\sigma(u)$, is exactly matched by construction. Vacancy volatility is slightly too large. The predicted correlation coefficient between unemployment and vacancies is negative as in the data, but close to zero. In the Appendix, we demonstrate that this result is due to the choice $\alpha = 1$. The correlation coefficient between unemployment and tightness is larger and more in line with the empirical one.

The key issue is aggregate persistence. The model does a fairly good job in fitting unemployment and vacancy persistence in five of the six OECD countries. However the predicted autocorrelation is negative in the US.

3.4 The determinants of unemployment persistence

For each country and for different possible values of δ and γ, Table 4 compares the predicted and actual persistence of unemployment. Table 2 confirms the results displayed by Proposition 3. Persistence decreases with the phantom death rate and job-finding rate. It also decreases with workers' bargaining power. In five out of the six countries, the quarterly

Figure 6: Unemployment persistence over the business cycle: data vs phantom cycles



autocorrelation parameter lies between 0.69 and 0.84 in our preferred configuration where $\delta = 1/2$ and $\gamma = 0.05$. In the US it is -0.12.

Figure 6 visually displays these findings. For each country, we highlight the empirical auto-correlation parameter. We then show the predicted autocorrelation parameter for the different values of δ and for $\gamma = 0.05$. The US case is striking, with predicted values well below the empirical one.

Table 4: Unemployment persistence: data vs phantom cycles

	Fra	Ger	Jap	Spa	UK	US
Data	0.90	0.93	0.85	0.94	0.93	0.91
Model with $\gamma = 10\%$						
$\delta = 1$	0.56	0.68	0.40	0.63	0.41	-0.74
$\delta = 1/2$	0.77	0.83	0.68	0.80	0.68	-0.19
$\delta = 1/3$	0.84	0.88	0.77	0.86	0.78	0.09
$\delta = 1/6$	0.91	0.94	0.88	0.93	0.88	0.44
$\delta = 1/12$	0.95	0.96	0.94	0.96	0.94	0.64
Model with $\delta = 1/2$						
$\gamma = 25\%$	0.74	0.81	0.63	0.78	0.64	-0.37
$\gamma = 10\%$	0.77	0.83	0.68	0.80	0.68	-0.19
$\gamma = 5\%$	0.81	0.84	0.69	0.81	0.70	-0.12
Model with $\delta = 1/3$						
$\gamma = 25\%$	0.82	0.87	0.74	0.85	0.75	-0.11
$\gamma = 10\%$	0.84	0.88	0.77	0.86	0.78	0.09
$\gamma = 5\%$	0.85	0.89	0.79	0.87	0.79	0.17
Model with $\delta = 1/6$						
$\gamma = 25\%$	0.90	0.93	0.86	0.90	0.86	0.25
$\gamma = 10\%$	0.91	0.94	0.88	0.93	0.88	0.44
$\gamma = 5\%$	0.92	0.94	0.89	0.93	0.89	0.52

Notes: This table reports the quarterly autocorrelation of unemployment in the data and during the various calibrated limit cycles. The calibration procedure is explained in the body text. In both cases, unemployment is hp-filtered with parameter $\lambda = 1,600$.

3.5 Robustness

In our calibrations, we make two strong choices regarding vacancy data. First, we suppose that these data are purged from phantoms and, therefore, only report available vacancies. Second, we normalize steady-state tightness to one in all countries. In this subsection, we examine alternative assumptions. Namely, we suppose that vacancy data actually report both phantoms and available vacancies, whereas tightness is allowed to vary across countries.

3.5.1 When vacancy data contain phantoms

We now consider the case where vacancy data include phantoms. Therefore, the vacancy statistics that we report correspond to $v + p$ and not simply v. We re-examine the model performances to account for this fact. We keep the same parametrization and compute $\sigma(v+p)$, $ac(v+p)$ and $cor(u,v+p)$ in lieu of $\sigma(v), ac(v)$ and $cor(u,v)$.

Table 5: BUSINESS-CYCLE PROPERTIES WITH PHANTOMS IN VACANCY DATA

	$\sigma(v+p)$	$\sigma(v)$	$ac(v+p)$	$ac(v)$	$cor(u,v+p)$	$cor(u,v)$
France	0.15	0.15	0.78	0.78	-0.07	-0.04
Germany	0.28	0.28	0.84	0.84	-0.07	-0.05
Japan	0.13	0.13	0.69	0.69	-0.08	-0.04
Spain	0.28	0.28	0.81	0.81	-0.10	-0.08
UK	0.17	0.18	0.70	0.70	-0.10	-0.05
US	0.10	0.12	-0.12	-0.12	-0.30	-0.10

Table 5 does not show major changes between the new results and the previous ones. In particular, the predicted volatility and autocorrelation of vacancies coincide. The absolute value of the correlation coefficient between vacancies and unemployment is larger than before in all countries. This effect is sizeable in the US where the coefficient drops from -0.1 to -0.3.

3.5.2 When the phantom proportion stays constant across countries

The normalization $\theta^* = 1$ implies that the steady-state p/v ratio coincides with the steady-state job-finding rate. We now discuss this property and examine a different parametrization where this ratio is fixed across countries.

The steady-state number of phantoms is $p = \sigma M$. As $v = \theta u$, we have $p/v = \sigma M/(\theta u)$. When $\sigma = \theta = 1$, we obtain $p/v = \mu$. It follows that countries with a high job-finding rate must feature a large phantom-to-vacancy ratio.

This property is not bad: our theory predicts that phantoms are a by-product of matching success. However, it means that we attribute all cross-country differences in job-finding rates to underlying differences in the scale parameter of the matching technology, A, or in the phantom-to-vacancy ratio, p/v.

We now follow a differente route. We actually fix p/v to the US ratio in all the other countries and let tightness adjust in each of them. We maintain the assumption $\theta^* = 1$ in the US so that $(p/v)_{US} = \mu_{US}$. In the the other countries we have $p/v = \mu/\theta = \mu_{US}$. Tightness is then $\theta = \mu/\mu_{US}$. Of course, it is well below one in all countries.

We re-run our simulations with this assumption. The resulting statistics coincide with the ones displayed by Table 3. The normalization choice, therefore, does not affect phantom cycles. This result can be understood from careful inspection of the Jacobian matrix of system (9)-(11) evaluated in steady state. Given our way to set the different parameters, this matrix does not depend on tightness. Therefore the normalization does not affect Hopf bifurcations and corresponding limit cycles.

4 Conclusion

Searching for partners involves treating information about market participants and supplying information about oneself. However, information survives market departure and becomes obsolete, thereby generating market frictions. In Chï¿½ron and Decreuse (2017), we name phantoms these traders of the past who leave tracks and negatively impact the current searchers. In this paper, we are interested in phantom cycles resulting from the interaction between phantom dynamics and firms' incentive to offer vacancies. We argue that phantom cycles provide a better description of aggregate fluctuations in sclerotic labor markets than in markets with high worker turnover. In other words, they suit better the French case than the US one.

During phantom cycles, firms concentrate vacancy creation at times where unemployment is low. Then phantoms accumulate, deteriorating the matching efficiency and leading to cycle reversal. Persistence of the vacancy-to-phantom ratio is key to reproduce the large persistence of unemployment and vacancies found in the data. In the US where worker turnover is particularly high, the latter ratio is largely impacted by the inflow of new vacancies and tends to be too procyclical as a result. To offset this effect, we need to increase the duration of obsolete information above realistic levels. The problem does not arise in the other countries where worker turnover is lower.

Of course, the cycles we describe are too regular to describe actual fluctuations. It could be worth combining them with aggregate shocks. In a different model, Beaudry et al (2018) show that such stochastic cycles can simultaneously capture the strong peaks in the frequency domain and generate irregular fluctuations as in actual data. They also show that transitory shocks have strong persistent effects, typically stronger than in saddle-path stable configurations. We suspect that these findings also apply to phantom cycles.

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A Proofs

All proofs involve the Jacobian matrix, J, of the dynamic system (9)-(11) evaluated in steady state:

$$J = \begin{bmatrix} \frac{I_{11}}{1-\varepsilon} & \frac{I_{12}}{1-\varepsilon} & \frac{I_{13}}{1-\varepsilon} \\ -\frac{\mu}{\theta}u\varepsilon & J_{22} & (\varepsilon-\alpha)/\sigma \\ 0 & \beta(\delta - s) & -\delta \end{bmatrix}, \tag{17}$$

with

$$
\begin{aligned}
I_{11} &= -(\mu+\delta)(\varepsilon-\alpha)\varepsilon+(r+s)(1-\varepsilon)+\gamma\mu, \\
I_{12} &= -\frac{(\mu+\delta)(\varepsilon-\alpha)\theta}{u\mu}\left[r+s+\mu+s+(\mu+\delta)(\varepsilon-\alpha)+\frac{\delta(\delta-s)}{\mu+\delta}\right], \\
I_{13} &= \frac{(\varepsilon-\alpha)\theta}{\mu\sigma u}[(\mu+\delta)(\varepsilon-\alpha)-\delta+r+s], \\
J_{22} &= -(s+\mu)-(\varepsilon-\alpha)(\mu+\delta),
\end{aligned}
$$

where ε stands for $\bar{\varepsilon}_v^{SR}$.

A.1 Proof of Proposition 1

(i) The eigenvalues solve ${}_i\lambda_i = T$, ${}_i\lambda_i^2 = Z$ and ${}_i\lambda_i = D$. In the case where λ_1 is real and $\lambda_2 = -\lambda_3 = ib$, $b > 0$, we have $\lambda_1 = T$, $\lambda_1^2 - 2b^2 = Z$ and $\lambda_1 b^2 = D$. Therefore $\lambda_1 = T < 0$, $b = \sqrt{D/T}$ and $T^2 - 2D/T = Z$.

(ii) The statement is true when $\delta \geq s$; otherwise $D > 0$. Now suppose that $\delta < s$ and $\varepsilon^H \leq 1$. We have

$$
\begin{aligned}
(1-\varepsilon)^2 Z &= [(1-\varepsilon)T+(\mu+\delta)(1-\alpha-\varepsilon(\varepsilon-\alpha))+s(1-\varepsilon)]^2 \\
&\quad +2\varepsilon(\varepsilon-\alpha)(1-\varepsilon)(\mu+\delta)[r+s+\mu+s+(\varepsilon-\alpha)(\mu+\delta)] \\
&\quad +(1-\varepsilon)^2[\mu+s+(\varepsilon-\alpha)(\mu+\delta)]^2 \\
&\quad +2(\varepsilon-\alpha)(1-\varepsilon)\delta(\delta-s)+(1-\varepsilon)^2\delta^2 \\
&> (1-\varepsilon)^2T^2+2s^2(1-\varepsilon)^2-2(\varepsilon-\alpha)(1-\varepsilon)s^2 \\
&> (1-\varepsilon)^2T^2.
\end{aligned}
$$

Therefore $Z - T^2 > 0$. In turn the equality $Z - T^2 = -2D/T$ implies that D and T have opposite signs, which is impossible.

A.2 Proof of Proposition 2

(i) When $\delta \to 0$, $D \to 0$ and there is a Hopf bifurcation when $r(1-\varepsilon)+(\gamma-1+\alpha)\mu > 0$, which ensures that $T < 0$, and $Z = T^2$. Solving gives $\varepsilon^H = ((1-\alpha)\mu+s)(\gamma\mu+r+s)/(s(r+s)-\gamma\mu^2)$, which requires that $s(r+s)-\gamma\mu^2 > 0$.

When $\delta \to \infty$, $(1-\varepsilon)T = r(1-\varepsilon)+\gamma\mu-(\mu+\delta)(1-\alpha) > 0$ implies that $\alpha = 1$. Therefore $(1-\varepsilon)T = r(1-\varepsilon)+\gamma\mu$ and $(1-\varepsilon)D \sim \delta\{(\mu+s)\gamma\mu\varepsilon+(\varepsilon-1)\varepsilon 2\delta^2\}$. Meanwhile,

(ii) Forthcoming

When μ and s tend to 0, $(1-\varepsilon)T = r(1-\varepsilon)+\gamma\mu-(\mu+\delta)(1-\alpha) > 0$ implies that $\alpha = 1$. It follows that $(1-\varepsilon)D \sim 2(\varepsilon-1)\varepsilon\delta^3$ and $(1-\varepsilon)T = r(1-\varepsilon)+\gamma\mu$. We also obtain that $(1-\varepsilon)^2 Z \sim \gamma^2\mu^2 - 2\gamma\mu(\varepsilon-1)(r+\delta)$. Then $(1-\varepsilon)^2(Z-T^2) \sim -r^2(\varepsilon-1)^2 - 2\gamma\mu(\varepsilon-1)\delta$. Therefore solving $(1-\varepsilon)^3(Z-T^2)T = -2D(1-\varepsilon)^3$ in ε gives

$$2\gamma\mu(\varepsilon-1)\delta[r(1-\varepsilon)+\gamma\mu] = 4(\varepsilon-1)^3\varepsilon\delta^3,$$

which is equivalent to

$$\gamma\mu[r(1-\varepsilon)+\gamma\mu] = 2(\varepsilon-1)^2\varepsilon\delta^2.$$

This implies that $\varepsilon^H \to 1$ as $\mu \to 0$. For μ sufficiently small, $\varepsilon - 1$ is equivalent to x, the solution of

$$2x^2\delta^2 + \gamma\mu r x + \gamma^2\mu^2 = 0.$$

This gives

$$x = \gamma\mu r \frac{(1 + 8(\delta/r)^2)^{1/2} - 1}{4\delta^2} < \gamma\mu/r.$$

Thus $r(1-\varepsilon) + \gamma\mu > 0$ and $T < 0$.

A.3 Proof of Proposition 3

(i) In the neighborhood of the Hopf bifurcation, the complex conjugate eigenvalues of J are $\lambda_2 = -\lambda_3 = i\sqrt{D/T}$. Therefore the period of the corresponding limit cycle is $P = 2\pi\sqrt{T/D}$. It follows that $P \to \infty$ as $T/D \to \infty$.

(ii) In the neighborhood of the bifurcation, the cycle period is

$$P = 2\pi\sqrt{T/D} \to 2\pi\sqrt{-\frac{r}{2\delta^3} + \frac{2}{\delta r[(1 + 8(\delta/r)^2)^{1/2} - 1]}}.$$

B Understanding the low correlation between unemployment and vacancies

Table 2 shows that the correlation coefficient between unemployment and vacancies is much larger (in absolute value) in the data than in our calibrated phantom cycles. In this Appendix, we argue this is so because of our choice $\alpha = 1$.

Consider the steady state of our model. We have

$$u = \frac{q}{q + \mu(\theta)}. \tag{18}$$

Moreover, $v = \theta u$. Thus

$$\frac{dv}{du} = \frac{d\theta}{du}u + \theta. \tag{19}$$

There are two terms. On the one hand, θ and u are negatively correlated in steady state, which tends to generate a negative correlation between u and v. On the other hand, an increase in u implies a similar increase in v at given θ, which tends to generate a positive correlation.

We can rewrite (19) under the form of an elasticity. This gives

$$\frac{u}{v}\frac{dv}{du} = \frac{u}{v}\frac{d\theta}{du}u + \frac{u}{v}\theta = \frac{u}{\theta}\frac{d\theta}{du} + 1. \tag{20}$$

Differentiating (18), we obtain

$$\frac{u}{\theta}\frac{d\theta}{du} = -\frac{q + \mu}{\theta\mu'(\theta)} = -\frac{q + \mu}{\alpha\mu}. \tag{21}$$

Therefore,

$$\frac{u}{v}\frac{dv}{du} = -\frac{q + (1-\alpha)\mu}{\varepsilon_v^{LR}\mu} < 0. \tag{22}$$

In steady state u and v are negatively correlated. Quantitatively, the elasticity depends on parameters ε_v^{LR}, q and μ. It decreases (in absolute value) with ε_v^{LR}.

We impose $\alpha = 1$, which implies that $\varepsilon_v^{LR} = 1$ as well. Therefore

$$\frac{u}{v}\frac{dv}{du} = -\frac{q}{\mu} = -\frac{u}{1-u}. \tag{23}$$

This elasticity cannot be directly compared to the correlation coefficient between u and v. Instead consider the following regression: $\ln v = a_0 + a_1 \ln u + e$. The OLS estimate of parameter a_1 is $\hat{a}_1 = cov(u,v)/\sigma(u)^2 = cor(u,v)\sigma(u)/\sigma(v)$. It follows that the correlation coefficient that we report must be compared to $-\frac{u}{1-u}\sigma(v)/\sigma(u)$. This value is above -0.2.

Put otherwise, the standard equilibrium search unemployment model predicts u and v are weakly correlated when the elasticity of the matching function with respect to vacancies is one. During phantom cycles, the average correlation coefficient between u and v is close to the stationary one. Therefore phantom cycles with $\alpha = 1$ predict that the correlation between u and v is tenuous.

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