Post-Pandemic Recovery: Search and Matching, Labor Productivity, and Coordination Effects

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Abstract

After the outbreak of the COVID-19 pandemic, in the United States output recovered quickly, labor productivity went up above the pre-pandemic trend, and the labor market was tight, all despite high unemployment. I explain these stylized facts in a canonical search and matching model of unemployment with two additional assumptions: endogenous labor demand and the presence of coordination effects. The first assumption allows firms to adjust to recessions instead of shutting down. The second assumption introduces strategic complementarity in firm entry: the larger the number of firms, the larger the demand for varieties of intermediate goods, and the smaller firm size will become sufficient to justify costly entry. Two regimes arise endogenously: a regime with weak coordination effects and a regime with strong coordination effects. The regime with weak coordination effects describes the pre-pandemic era and the regime with strong coordination effects describes the post-pandemic period. Under strong coordination effects, when a job separation shock realizes, new firms find it easier to hire workers. As firms enter, they post vacancies, and the labor market becomes tight. Under strong coordination effects, the model also predicts the net creation of establishments, an increase in labor productivity and in producer prices, and a reduction in the average firm size in response to a job separation shock, as found in the post-pandemic data.

Keywords: COVID-19, labor productivity, firm entry, unemployment, search and matching, coordination. **JEL Codes:** E24, E32, L11

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1 Introduction

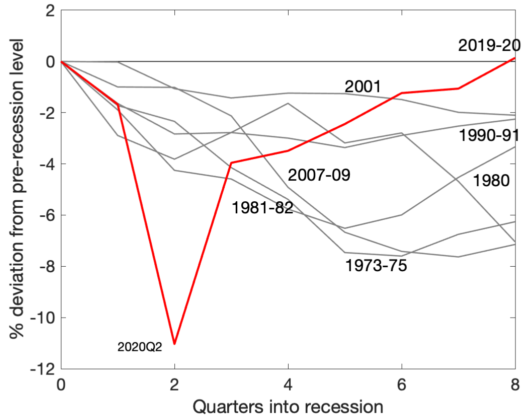
The outbreak of the COVID-19 pandemic in 2020 caused a sharp economic recession with dramatic losses in output and a record-high unemployment rate. This recession and the recovery differ from a typical business cycle in the United States in several important ways. Firstly, the spike in the unemployment rate caused only a short-lived decrease in output. Fig. 1(a) shows that real GDP reached the pre-crisis trend faster than after any other recession in the past fifty years. Real GDP per size of the labor force not only recovered quickly, but it also continued to grow above the pre-pandemic level (see Fig. 1(b)). Secondly, following the initial drop in the second quarter of 2020, the aggregate labor productivity (real GDP to employment ratio) substantially increased above the pre-pandemic trend (see Fig. 1(c)). Table 1 breaks down labor productivity by industry. For most industries, annual productivity recovered relatively to 2019 even by the end of 2020, and continued to grow.[1] Finally, the labor market was tight in spite of high unemployment; the vacancy rate increased substantially. The Beveridge curve shifted outwards (see Fig. 2). These stylized facts present a challenge for the search and matching theory of unemployment (Diamond (1982), Mortensen and Pissarides (1994)) where high unemployment is usually related to persistent recessions, low productivity, and a loose labor market.

I show how the canonical Diamond-Pissarides-Mortensen (DMP) can explain both the pre-pandemic business cycle and the the post-pandemic recovery when two assumptions are added: endogenous labor demand and the presence of coordination effects. The first assumption, endogenous labor demand, enables firms with a margin of adjustment that is absent in the DMP model. Firms pick their size to make sure that their revenue is sufficiently high to justify costly entry. When the economy is in a recession, firms can change their size and continue operating instead of shutting down completely.

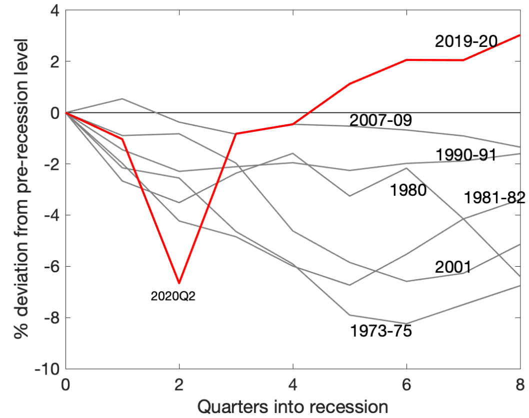
The second assumption, coordination effects, creates strategic complementarity in firm entry: each firm generates more revenue as new firms are created. The final good is assembled from differentiated varieties of intermediate goods produced by monopolistically competitive firms. Consumers have a taste for variety, and the creation of new varieties raises the demand for *all* varieties. Therefore, as firms enter, prices for all varieties go up, and all firms generate higher revenue.[2] The output-to-labor ratio becomes positively related to the

[1] Ascari, Colciago, and Silvestrini (2023) find a correlation between the initial productivity drop and the exposure to COVID.

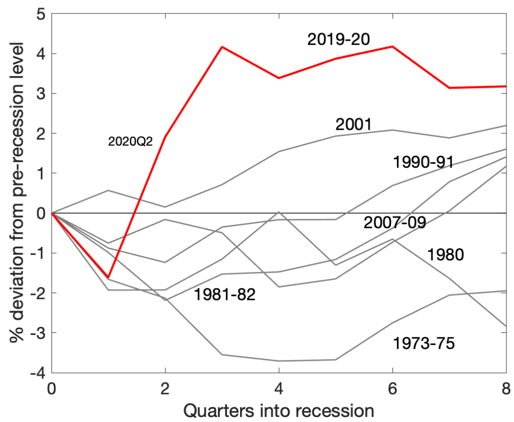
[2] Because each variety is produced by a monopolist, the prices set by firms are positively related to the aggregate demand which in turn depends on the number of varieties via the taste-for-variety assumption. Since each variety is produced by a single firm, the prices are positively related to the measure of firms. Firm entry does not cause a decrease in prices because each firm operates on its own market, and there is no intra-industry competition. Amir and Lambson (2000) study the effects of entry on prices and quantities



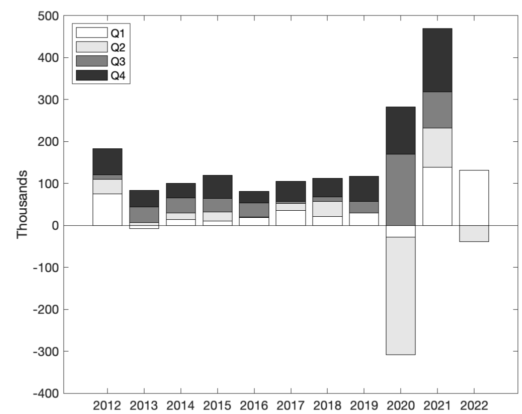
(a) Real GDP



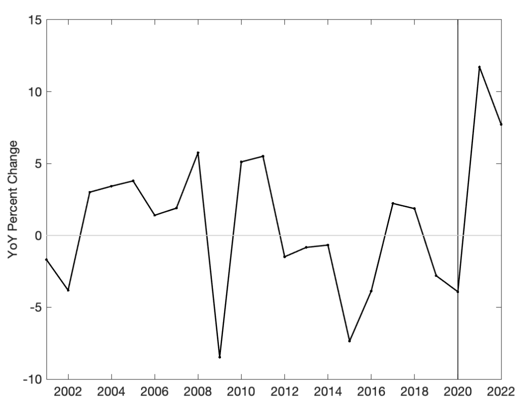
(b) Real GDP per Labor Force Size



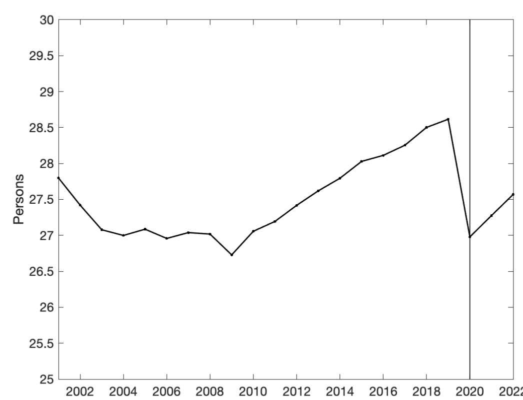
(c) Real GDP per Worker



(d) Net Creation of Establishments



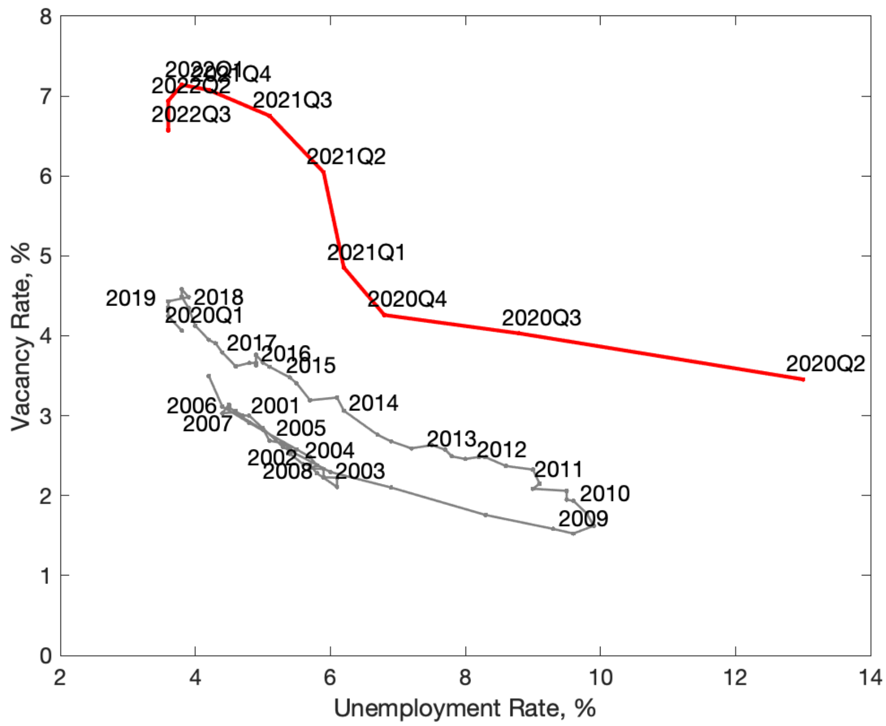
(e) PPI/CPI Ratio



(f) Average Firm Size

Source: BEA, BLS. Real GDP and labor data are log-linearly detrended; percentage deviations are from the pre-2020 trend

Figure 1: Stylized Facts about Post-Pandemic Recovery



Source: BLS.

Figure 2: Outward Shift in the Beveridge Curve

measure of firms.

My model predicts that there is an inverse relationship between the measure of firms and the size of each firm. Due to the coordination effects, when firms enter and therefore when the prices go up, firms will become smaller because the same revenue can be achieved with fewer workers. The effect of firm entry on total employment is generally ambiguous, however: it depends on how strong the coordination effects are. There are two forces. On the one hand, entrants hire new workers and add to the total employment. On the other hand, incumbents downsize and seek to hire fewer workers. There is an endogenous threshold where these two forces balance each other out, and this threshold gives rise to two regimes: a regime with *weak coordination effects* and a regime with *strong coordination effects*. Depending on the size of the elasticity of the demand, the economy finds itself in one of these two regimes.

The strength of the coordination effects is measured by the price elasticity of the demand for each variety. The monopolistic competition allows firms to set their own prices, but the substitutability of varieties makes firms coordinate on prices. The higher the elasticity of the demand, the less market power firms have, and the smaller are incentives for firms to

in a Cournot setup when there are several firms in the same market.

Industry	Productivity Growth, %		Share in GDP, %
	2020	2021	2019
Agriculture, forestry, fishing, hunting	5.1	−7.7	0.7
Mining	23.7	−11.8	1.4
Utilities	4.6	−4.3	1.5
Construction	−0.2	−0.4	4.2
Manufacturing	0.9	4.8	11.1
Wholesale trade	4.7	4.1	6.0
Retail trade	2.8	−1.3	5.5
Transportation and warehousing	−12.5	0.4	3.2
Information	9.3	8.7	5.3
Finance, insurance, real estate, rental, leasing	1.1	3.4	21.0
Professional and business services	0.9	6.2	12.7
Educational services, health care, social assistance	0.4	2.3	8.8
Arts, entertainment, recreation, accommodation, food services	−6.8	16.1	4.3
Other services, except government	0.7	3.7	2.1
Federal government	1.0	1.8	3.8
State and local government	1.7	0.6	8.5

Source: BEA. Productivity is measured as real value added divided by employment.

Table 1: Labor Productivity Growth by Industry

coordinate on price setting. In a limiting case when the elasticity tends to infinity, my model collapses to the DMP model, and the coordination effects vanish. The regime with weak coordination effects arises when the elasticity of demand is above a certain endogenously determined threshold and the regime with strong coordination effects arises when the elasticity of demand is below that threshold. Under weak coordination effects, firm entry drives total employment up, in spite of labor displaced from incumbents. Under strong coordination effects, firm entry drives total employment down: firms generate more revenue than before, and more workers are laid off by incumbents than workers hired by entrants.

The two-regime property of the model naturally helps to differentiate the pre-pandemic era and the post-pandemic recovery within a unified model. I argue that the model with weak coordination effects describes the business cycle before 2020 and a model with strong coordination effects explains the post-pandemic period. There are two reasons why. Firstly, we can use the cyclical properties of firm entry to identify the strength of coordination effects. Under weak coordination effects, firm entry is pro-cyclical in the model, and this is the pattern found in the pre-pandemic data (Jaimovich and Floetotto (2008), Tian (2018)). Instead, firm entry and concurrent high unemployment, i.e. a situation during the post-pandemic recovery, is consistent with strong coordination effects (see Fig. 1(d) and also Crane, Decker, Flaaen, Hamins-Puertolas, and Kurz (2022)). Secondly, if coordination effects are considered more broadly as synchronization of business decisions across firms, there is evidence that synchronization increased with the outbreak of the pandemic. Unprecedented regulation from local authorities and pervasive guidance from public health officials synchronized business practices in nearly all industries, making the coordination effects stronger than before the pandemic. This idea is borne out in the data: Goolsbee and Syverson (2021), Forsythe, Kahn, Lange, and Wiczer (2020), Kong and Prinz (2020) show that a substantial portion of the layoffs in March-April of 2020 was due to synchronized firms' decisions; firms laid off workers even in industries and counties without severe stay-at-home orders.

I model the economic crisis of 2020 as a job separation shock, i.e. a shock that relocates workers from the pool of employed to the pool of unemployed.[3] While the change in the regime could be a shock itself, I instead imagine that there are two economies, one with weak coordination effects and one with strong coordination effects, and I study the consequences of a job separation shock in each of the two economies. I also consider a third economy where there are no coordination effects (i.e. the DMP model). In the DMP model, a job separation rate causes high unemployment but it also makes firms shut down, causes a loose labor market (a low vacancy-to-unemployment ratio), and a drop in output. My model shows similar effects under weak coordination effects. Under strong coordination effects, however, the predictions of the model change. As a job separation shock occurs and there becomes a bigger pool of unemployed workers available for hire, new firms enter, the producer prices go up, and, via the coordination effects, the firm size goes down. New firms post vacancies, and the labor market becomes tight, in spite of high unemployment. This logic is supported by the data: Fig. 1(f) shows that there was a sharp reduction in the average size of firms in 2020, and Fig. 1(e) shows that the producer prices rose in 2020 relative to consumer prices.

There are multiple ways to model recessions caused by a public health crisis. A growing literature augments general-equilibrium theories with an epidemiological block.[4] Another direction in the literature treats the pandemic as a demand-side or supply-side shock.[5] This paper considers a job separation shock. The shock to the job separation rate captures production-side government restrictions, initial firm layoffs, and a decrease in the consumer demand for labor-intensive goods (e.g. services and entertainment).

My work is closely related to two papers. The coordination effects are modeled similarly to Schaal and Taschereau-Dumouchel (2016) and Sniekers (2018). Schaal and Taschereau-Dumouchel (2016) add monopolistic competition and taste for variety to the otherwise stan-

[3] I abstract from the effect of the pandemic on the participation rate, assuming that all relevant variables in the model are divided by the size of the labor force.

[4] For instance, Ascari, Colciago, and Silvestrini (2023), Benmir, Jaccard, and Vermandel (2023), Kapička and Rupert (2022), Lepetit and Fuentes-Albero (2022).

[5] Baqaee and Farhi (2022) and Eichenbaum, Rebelo, and Trabandt (2022) view the pandemic as a simultaneous shock to the aggregate demand and aggregate supply. Bonadio, Huo, Levchenko, and Pandalai-Nayar (2021) studies the effects of a labor supply shock. Caballero and Simsek (forthcoming) and Guerrieri, Lorenzoni, Straub, and Werning (2022) consider negative productivity shocks. In Woodford (2022), the pandemic disrupts the circular flow of payment. Ravenna and Walsh (2022) assume a preference shock towards leisure and a job separation shock.

dard DMP model. They show that their model helps to resolve the Shimer puzzle (Shimer (2005)).[6] They also note that there may be multiple steady-state equilibria due to strategic complementarity in the entry decision. Sniekers (2018) studies the conditions under which there are multiple steady states in this model and also shows that the model can produce pre-pandemic business cycles as a limit cycle. My work builds on these papers. Firstly, I add endogenous labor demand to these models and I study the interaction between the coordination effects and the firm size, with new non-trivial implications. Secondly, since both these papers assume a fixed firm size, the coordination effects would be described as weak in their models. By allowing for endogenous firm size, I expand the analysis and consider both regimes: weak and strong coordination effects. Finally, I show analytically that there is a unique steady state under strong coordination effects.

My model borrows the concept of endogenous labor demand from Smith (1999). Smith shows that when the standard DMP model is augmented with a neoclassical labor choice in firms, the labor demand will be constant. By allowing for coordination effects, I make the labor demand state-contingent: the measure of firms affects each individual firm's size through the price of each variety and its effect on the firm revenue.

My model is also related to Lazaryan and Lubik (2019) from where I use the formulation of the search and matching model in discrete time and to Lubik (2009) which solves a DMP model with monopolistic competition (but without endogenous firm size and without coordination effects).

The paper is organized as follows. Section II presents the model. Section III simulates the model. Section IV concludes.

2 Model

2.1 Labor Market

Time is discrete and never ends: $t = 0, 1, 2 \ldots$. There is perfect foresight. There is a unit continuum of risk-neutral households and an endogenous measure m_t of risk-neutral firms. Workers can be either employed or unemployed. Let N_t denote the number of employed workers and U_t denote the number of unemployed workers:

$$N_t + U_t = 1. \tag{1}$$

[6] The idea that monopolistic competition creates aggregate-demand externalities is also discussed in Blanchard and Kiyotaki (1987). Bilbiie, Ghironi, and Melitz (2012) study the effects of taste for variety in a general equilibrium model with labor market clearing (i.e. without unemployment). Pavlov (2021) shows how the taste for variety may amplify the business cycle.

The search and matching frictions follow the DMP tradition. There is a matching process described by an increasing, quasi-concave and homogeneous of degree one matching function $M(U_t, V_t)$ where V_t is the vacancy rate. The labor market tightness is defined as $\theta_t = V_t/U_t$. Firms fill a vacancy with probability

$$q(\theta_t) \equiv \frac{M(U_t, V_t)}{V_t} = M\left(\frac{1}{\theta_t}, 1\right) \tag{2}$$

and unemployed workers find a job with probability

$$f(\theta_t) \equiv \frac{M(U_t, V_t)}{U_t} = M(1, \theta_t). \tag{3}$$

The properties of the matching function imply that $f(\theta_t) = \theta_t q(\theta_t)$, that $q(\theta_t)$ is decreasing in θ_t and that $f(\theta_t)$ is increasing in θ_t.

When I solve the model numerically, I adopt

$$M(U_t, V_t) = \chi U_t^{\xi} V_t^{1-\xi}.$$

where $0 < \xi < 1$ and $\chi < 1$ is a scale parameter. The implied vacancy-filling rate and job-finding rate become

$$q(\theta_t) = \chi\theta_t^{-\xi}, \quad f(\theta_t) = \chi\theta_t^{1-\xi}.$$

While there is no guarantee that the matching probabilities $q(\theta)$ and $f(\theta)$ will stay within the unit interval for all values of θ, I calibrate the model to a steady state where these probabilities are less than 1, and I consider only small deviations from the steady state.

At the beginning of every period, incumbent firms lose a fraction s_t of the employed workers due to exogenous job separation. Those workers become unemployed. Within the period, firms hire new workers who will become productive only in the next period. The law of motion for total employment is given by

$$N_t = (1 - s_t)\left[N_{t-1} + f(\theta_{t-1})(1 - N_{t-1})\right]. \tag{4}$$

2.2 Production of the Final Good and the Coordination Effects

This section follows Schaal and Taschereau-Dumouchel (2016). Sniekers (2018) adopts the same specification by assumption. The final (consumption) good Y_t is produced from a continuum of varieties of intermediate goods indexed by $j \in [0, m_t]$ where m_t is the endogenous measure of intermediate goods:

$$Y_t = \left(\int_0^{m_t} y_t(j)^{\frac{1}{1+\gamma}} dj \right)^{1+\gamma}. \tag{5}$$

Here $\gamma > 0$ and $\sigma \equiv (1+\gamma)/\gamma > 1$ measures the elasticity of substitution across goods.

The cost of one unit of the final good depends on the prices of intermediate goods $p_t(j)$:

$$P_t = \left(\int_0^{m_t} p_t(j)^{-1/\gamma} dj \right)^{-\gamma}. \tag{6}$$

I assume that all firms will make the same decisions; therefore, index j will be omitted from now on. Let the final good be the numeraire: $P_t = 1$ for all t. The demand for every variety becomes

$$y_t = p_t^{-\frac{1+\gamma}{\gamma}} Y_t. \tag{7}$$

Here p_t is the relative price set by every monopolist. From (6), the price of each variety is now related to the measure of firms:

$$p_t = m_t^{\gamma}, \tag{8}$$

and each firm's revenue becomes

$$p_t y_t = m_t^{\gamma} y_t. \tag{9}$$

Equation (9) demonstrates the coordination effects: each firm's revenue is positively related to the measure of firms m_t, and γ is the elasticity of the revenue with respect to the measure of firms. More generally, the parameter γ measures the strength of the coordination effects. In the standard DMP model, the economy is perfectly competitive and $\gamma \to 0$. The bigger γ, the higher is the positive effect of firm entry on the revenue, even if firms keep output unchanged. The reason for the positive elasticity stems from the taste for variety assumption: as firms enter and new varieties are created, the demand for *all* varieties goes up, allowing *all* firms to raise their prices.

2.3 Incumbent Firms

Each incumbent firm produces a unique variety $j \in [0, m_t]$ and operates as a monopolist in her own industry. To simplify notations, I omit the indexing of firms as all incumbent firms will make the same economic decisions.

The production function is neoclassical:

$$y_t = n_t^{1-\alpha} \tag{10}$$

where y_t and n_t are production and labor for each firm respectively. I assume the production function is a power function.[7] Hired workers are paid a wage w_t quoted in terms of the final good.

Each firm's labor is predetermined. In order to hire workers, firms must post vacancies v_t. The cost of posting a vacancy is $\kappa > 0$. Each firm's labor follows the law of motion

$$n_t = (1 - s_t)\left[n_{t-1} + q(\theta_{t-1})v_{t-1}\right]. \tag{11}$$

Firms discount the future at a constant rate $0 < \beta < 1$ and maximize their value J_t defined recursively as follows:

$$J_t(n_t) = p_t n_t^{1-\alpha} - w_t n_t - \kappa v_t + \beta J_{t+1}(n_{t+1}) \tag{12}$$

subject to (7), (10) and (11) by choosing $\{n_{t+1}, p_t, y_t, v_t\}$ given n_t. Note that equation (6) holds only at equilibrium and is not internalized by firms. The first-order conditions are

$$\beta J'_{t+1}(n_{t+1}) = \tau_t, \tag{13}$$

$$J'_t(n_t) = -w_t + \lambda_t \cdot (1-\alpha) n_t^{-\alpha} + (1 - s_t)\tau_t, \tag{14}$$

$$\lambda_t = \frac{1}{1+\gamma} \cdot p_t, \tag{15}$$

$$-\kappa + \tau_t(1 - s_t)q(\theta_t) = 0. \tag{16}$$

Here the variable τ_t is the Lagrange multiplier on the law of motion for labor (11) and shows the marginal value of a worker to the firm. The variable λ_t is the shadow cost of output to the firm as the Lagrange multiplier on the combined constraints (7) and (10)

$$n_t^{1-\alpha} = p_t^{-\frac{1+\gamma}{\gamma}} Y_t.$$

Equation (13) is the first-order condition with respect to n_{t+1}. It says that the shadow value of a worker is equal to the future discounted marginal value of the worker. Equation (14) is the envelope condition for n_t. It dictates that the marginal value of workers consists of the instantaneous marginal revenue product of labor, savings from keeping the worker employed minus labor costs, i.e. wage. Equation (15) is the first-order condition with respect to the price p_t chosen by the monopolist. It trades off the marginal revenue, given as a fraction of the price, and the shadow cost of output. Finally, equation (16) is the first-order condition

[7] The results of this paper would hold for any increasing and concave production function. I use a power function to simplify the exposition.

with respect to v_t: it trades off the instantaneous costs of posting a vacancy and the future marginal effect of a hired worker on the value of the firm.

When combined, the first-order conditions constitute the Job Creation Condition:

$$\beta \left(\frac{1-\alpha}{1+\gamma} \cdot p_{t+1} n_{t+1}^{-\alpha} - w_{t+1} + \frac{\kappa}{q(\theta_{t+1})} \right) = \frac{\kappa}{(1-s_t) q(\theta_t)}. \tag{17}$$

Equation (17) determines the willingness of firms to post vacancies. Firms trade off the instantaneous expected costs of posting a vacancy on the right-hand side of (17) (where the expectation is taken with respect to the time to fill a vacancy) and the future benefits of having a vacancy filled, given by the future marginal revenue product of labor minus wage plus future savings on hiring costs.

2.4 Entry and the Value of Firms

New firms can enter at any time by paying a fixed sunk entry cost $c > 0$. Upon entry, entrants post vacancies. Production will take place only in the next period. Since there are no borrowing constraints for entrants, entrants will post the number of vacancies v_t^e such that they catch up with incumbents by the next period, and the continuation value is the same as of incumbents, $J_{t+1}(n_{t+1})$. The value of an entrant, J_t^e, is thus given by

$$J_t^e = -\kappa v_t^e - c + \beta J_{t+1}(n_{t+1}) \tag{18}$$

where

$$n_{t+1} = (1 - s_{t+1}) q(\theta_t) v_t^e. \tag{19}$$

New firms will be entering until $J_t^e = 0$.

Combining (12) and (18) with (11) and (19) yields the value of incumbents $J_t(n_t)$:

$$J_t(n_t) = p_t n_t^{1-\alpha} - w_t n_t + \frac{\kappa n_t}{q(\theta_t)} + c \tag{20}$$

Equation (20) states that the value of an incumbent is given by an incumbent's advantage over entrants. There are three terms in this expression: production-related profits ($p_t n_t^{1-\alpha} - w_t n_t$), savings on hiring costs, $\kappa n_t / q(\theta_t)$, and the shield caused by the entry cost c. The economic logic is straightforward: As opposed to entrants, incumbents can produce instantly, do not need to spend resources on hiring, and do not need to pay the entry costs. Note that future profits do not appear in the value of incumbents equation as the value of future profits is driven down to zero by current entrants.

Now I derive the entry condition. Firstly, I combine (18), (19), and (20) and use $J_t^e = 0$ to arrive at

$$\beta \left(p_{t+1} n_{t+1}^{1-\alpha} - w_{t+1} n_{t+1} + \frac{\kappa n_{t+1}}{q(\theta_{t+1})} \right) = \frac{\kappa}{(1-s_t) q(\theta_t)} + (1-\beta) c$$

Secondly, I combine the condition above with the Job Creation Condition (17) to arrive at the Entry Condition:[8]

$$p_{t+1} n_{t+1}^{1-\alpha} = \frac{1-\beta}{\beta} \cdot \frac{1+\gamma}{\alpha+\gamma} \cdot c \equiv R. \tag{21}$$

The Entry Condition (21) determines the labor demand. The size of each firm is characterized by the entry costs c, the future price p_{t+1}, and the elasticity of the production function $(1-\alpha)$.

If there were no coordination effects and the economy was perfectly competitive, the price of each variety would be equal to 1 (see eq. (8)). The Entry Condition (21) states then that the size of each firm would be time-invariant. This is the result obtained in Smith (1999). Changes in the conditions of the labor market would not affect the firm size. When coordination effects are present, the firm size depends on the price monopolists can charge which, in turn, depends on the measure of firms via (8).

Proposition 1 *When coordination effects are present, there is a negative relationship between the firm size n_{t+1} and the measure of firms m_{t+1}. Furthermore,*

$$\frac{dn/n}{dm/m} = -\frac{\gamma}{1-\alpha}. \tag{22}$$

Equation (22) shows how the percentage change in the firm size compares to the percentage change in the measure of firms. Before I discuss this ratio, I formally define strong and weak coordination effects.

Definition 1 *The coordination effects are strong if $\gamma > 1-\alpha$. The coordination effects are weak if $\gamma < 1-\alpha$.*

Definition 1 helps to develop the intuition behind Proposition 1. When new firms enter, they cause spillover effects, and all firms earn more revenue. Therefore, a smaller firm size becomes sufficient to meet the entry barrier. Under strong coordination effects, the percentage change in the firm size is greater than the percentage change in the measure of firms. Under weak coordination effects, the firm size changes less than the measure of firms.

[8] See Smith (1999) for the derivation of this condition for a general production function.

Proposition 1 helps to determine how total employment, $N = mn$, is split between m and n:

$$\frac{dN/N}{dm/m} = 1 - \frac{\gamma}{1-\alpha}.$$

Proposition 2 *If the coordination effects are strong, there is a negative link between the measure of firms and total employment. If the coordination effects are weak, there is a positive link between the measure of firms and employment.*

The logic of Proposition 1 builds on Proposition 1. When the coordination effects are strong, employment gained due to firm entry is smaller than employment lost due to the downsizing of incumbents. Total employment will decrease, and the unemployment rate will go up. When the coordination effects are weak, employment gained due to firm entry is higher than employment lost due to the downsizing of incumbents. Total employment will increase, and the unemployment rate will decrease.

2.5 Wage Determination

As in the standard DMP model, I assume that the wage is determined through a Nash bargaining process. I also assume that all workers earn the same wage. If η is the bargaining power of workers and $(1-\eta)$ is the bargaining power of firms $(0 < \eta < 1)$, then the wage becomes

$$w_t = \eta \left(\frac{1-\alpha}{1+\gamma} \cdot p_t n_t^{-\alpha} + \kappa\theta_t \right) + (1-\eta) b \tag{23}$$

where b is a worker's outside payoff. As in the DMP model, the wage is a weighted average of the marginal revenue product of labor inclusive of the "rent" term $\kappa\theta_t$ and the worker's outside payoff. The discrete-time derivation of the wage under Nash bargaining is provided in Lubik (2009).

2.6 Output and Aggregate Labor Productivity

In this subsection, all variables pertain to time $t+1$, and I omit the time index for clarity. Firstly, use (5) to write the final output at a symmetrical point:

$$Y = m^{1+\gamma} y. \tag{24}$$

Due to the taste-for-variety assumption, as the measure of firms goes up, the final output goes up more than one-for-one keeping each firm's production the same.

Variables	Coordination effects Absent $\gamma = 0$	Weak $0 < \gamma < 1-\alpha$	Strong $\gamma > 1-\alpha$
n and m	0	$-$	$-$
N and m	$+$	$+$	$-$
N and n	0	$-$	$+$
Y/N and m	0	$+$	$+$
Y/N and n	0	$-$	$-$

n = firm size, m = measure of firms, N = total employment, Y/N = aggregate labor productivity

Table 2: Coordination Effects: Summary

Next, divide both sides of the equation above by $N = mn$. The new expression shows how aggregate labor productivity is related to each firm's labor productivity.

$$\frac{Y}{N} = m^{\gamma} \cdot \frac{y}{n}. \tag{25}$$

Proposition 3 *When there are no coordination effects ($\gamma = 0$), aggregate labor productivity is constant. When the coordination effects are present ($\gamma > 0$), aggregate labor productivity is positively related to the measure of firms.*

Keeping each firm's output-to-labor constant, aggregate productivity is increasing in the measure of firms. This is a direct result of the taste-for-variety assumption. When $\gamma = 0$, the term m^{γ} vanishes but also each firm's size becomes constant (see proposition 1). Therefore, aggregate labor productivity will be constant too. When the coordination effects are present, they act as a positive externality. The effect of firm entry on aggregate productivity is even larger if each firm's production function is concave and therefore the average product of labor is diminishing. In addition to the externality effect, as new firms enter, the firm size will become smaller according to (21), and each firm's output-to-labor ratio will increase, contributing to aggregate productivity.

Table 2 summarizes the role of the coordination effects.

2.7 Definition of Dynamic Equilibrium

Definition 2 *A dynamic equilibrium is a collection $\{\theta_t, m_t, N_{t+1}\}_{t=0}^{\infty}$ such that given N_0, the Job Creation Condition, the Free Entry Condition, the law of motion for total employment and boundary conditions hold:*

$$\frac{(1-\alpha)(1-\eta)}{1+\gamma} m_{t+1}^{\gamma} \left(\frac{N_{t+1}}{m_{t+1}}\right)^{-\alpha} - \kappa\eta\theta_{t+1} - (1-\eta)b + \frac{\kappa}{q(\theta_{t+1})} = \frac{\kappa}{\beta(1-s_t)q(\theta_t)}, \tag{26}$$

$$m_{t+1}^{\gamma}\left(\frac{N_{t+1}}{m_{t+1}}\right)^{1-\alpha} = R, \tag{27}$$

$$N_t = (1 - s_t)\left[N_{t-1} + f(\theta_{t-1})(1 - N_{t-1})\right], \tag{28}$$

$$\lim_{t\to\infty} \theta_t < \infty, \quad \lim_{t\to\infty} m_t < \infty. \tag{29}$$

Equation (26) is the Job Creation Condition combined with wage (23) and where I substitute for the firm size. Equation (27) is the firm entry condition (21) where I substitute for the price and the firm size. Finally, equation (28) is the law of motion of total employment re-written here for convenience.

3 Analysis

3.1 Steady State

Proposition 4 *When the coordination effects are strong, there exists a unique steady state.*

To prove this result, note that, at steady state, (27) determines a decreasing function $m(N)$; (28) determines an increasing function $\theta(N)$. Then (26) becomes an equation in N where the left-hand side is decreasing in N and the right-hand side is increasing in N, hence a unique solution.

Multiplicity of steady-state equilibria frequently arises under coordination effects. Schaal and Taschereau-Dumouchel (2016) and Sniekers (2018) find multiplicity of steady states in a search and matching model with the same aggregate demand channel as in my model. Their model is a special case of my model where each firm's size is exogenously kept constant. Since firm entry has no effect on the firm size in their models, using the terminology of my paper, coordination effects in their model are "weak," and Proposition 3 does not apply.

3.2 Methodology and Calibration

I solve the model numerically. Table 3 displays the calibrated values of parameters. To illustrate the difference between the pre-pandemic era and the post-pandemic recovery, I compare two solutions: under weak coordination effects[9] (before the pandemic) and under

[9]When the coordination effects are weak, the model has two steady states, similarly to Sniekers (2018). However, at the second steady state, the unemployment rate is nearly 100% and output is nearly zero. I, therefore, focus on the other, economically meaningful steady state. Sniekers (2018) makes both steady states economically meaningful by adding endogenous search effort.

strong demand effects (the post-pandemic recovery). I also compare these solutions to the DMP model.

I linearize the model around the steady state and study the dynamics under the following scenario: the job separation rate goes up by 1 percentage point and gradually returns to the initial value.

One period is one quarter. Hagedorn and Manovskii (2008) reports a monthly job separation rate of 0.026. Den Haan, Ramey, and Watson (2000) reports a monthly job-filling rate of 0.71. Shimer (2005) reports the job-finding rate of 0.45. At the quarterly frequency, these rates become $s = 0.047$, $q = 0.976$, and $f = 0.834$. This also implies that the steady-state labor market tightness is $\theta = f/q = 0.855$. Borrowing $\xi = 0.72$ from Shimer (2005), I find that at the steady state $\chi = 0.87$.

Following Den Haan, Ramey, and Watson (2000), the curvature of the production function is set at $\alpha = 0.36$. The time preference parameter is $\beta = 0.99$.

The entry cost is chosen to normalize the marginal revenue product of labor to 1. For the regime with strong coordination effects, I set $c = 57.64$. For the regime with weak coordination effects, I use $c = 29.92$. In the DMP model, I set $c = 0$ as the entry costs are already captured by the vacancy creation costs κ. In all cases, I target the vacancy cost-to-wage ratio of 0.22 and the non-employment payoff-to-wage ratio of 0.41 as in Shimer (2005). This produces $b = 0.39$ and $\kappa = 0.22$.

I consider three values for the strength of coordination effects γ. For the regime with weak coordination effect times, I use $\gamma = 0.3$ which corresponds to the elasticity of substitution $\sigma = 4$, a value supported empirically (Broda and Weinstein (2006)) and typically used in the macro literature. For the regime with strong coordination effects, I set $\gamma = 0.67$, a value above $1 - \alpha$, so that the coordination effects become strong.[10] In the DMP model, there are no coordination effects, and $\gamma = 0$.

3.3 Dynamic Response to Job Separation Shock

The economy starts at the steady state. At time 1, the sequence for the separation rate s_t becomes

$$s_t = 0.5s + 0.5s_{t-1}, \quad s_0 = s + 0.01.$$

Figure 3 plots the impulse response functions. The horizontal axis indicates time, and the vertical axis measures the percentage change from the steady state (for the matching probabilities f_t and q_t, the vertical axis measures deviations from the steady state).

[10] I am not aware of any studies that estimate the price elasticity or the market power after 2020. Therefore, I pick a value for γ that would ensure that the coordination effects are strong.

Parameter		Value
Marginal revenue product of labor	$\frac{1-\alpha}{1+\gamma}pn^{-\alpha}$	1
Curvature of the production function	α	0.36
Time preference	β	0.99
Steady-state matching efficiency	χ	0.87
Elasticity of the matching function	ξ	0.72
Strength of coordination effects	γ	Strong effects: 0.67
		Weak effects: 0.30
		DMP: 0
Cost of vacancy	κ	0.22
Outside payoff for workers	b	0.39
Steady-state job separation rate	s	0.05
Bargaining power of workers	η	0.75
Entry costs	c	Strong effects: 57.64
		Weak effects: 29.92
		DMP: 0

Table 3: Calibration

Panel (a) shows the value of an incumbent. At time 1, incumbents lose a big portion of employees, and the value of firms goes down. The effect is the largest for the DMP model because firms have no margins to adjust. The effect is much smaller in my model because firms can change their size in response to unfavorable macroeconomic conditions. Over time, the value of firms returns to the steady state.

Panel (b) shows the measure of firms. At time 1, there is no change in the measure of firms in my model because the measure of firms is predetermined. The measure of firms in the DMP model instantly drops due to the assumption that one firm is made up of one worker. In period 2, firms enter if the coordination effects are strong and firms exit if the coordination effects are weak.

Panel (c) shows the firm size. In the DMP model, the firm size shows no change because it is normalized to 1. In my model, at time 1, the firm size goes down because firms lose workers. If the coordination effects are strong, the firm size decreases even more at time 2 due to the entry of new firms. If the coordination effects are weak, the firm size goes up and exceeds the initial level.

Panel (d) shows the producer price (consumption is the numeraire). In the DMP model, the price shows no change because it is normalized to 1. In my model, the price is determined by the measure of firms via the coordination effects. Under strong coordination effects, firms enter, and the price goes up. Under weak coordination effects, firms exit, and the price goes down.

Panel (e) shows output. At time 1, output drops because firms lose labor. If the coordination effects are strong, output goes up at time 2 due to firm entry and remains elevated until the economy returns to the steady state. If the coordination effects are weak, output falls even more due to firm exit and then gradually recovers. In the DMP model, output gradually recovers starting from time 2 as the economy converges to the steady state.

Panel (f) shows the unemployment rate. The unemployment rate spikes at time 1 due to the job separation shock. If the coordination effects are strong, the unemployment rate declines quickly and remains low as entering firms hire the unemployed. If the coordination effects are weak, unemployment continues to increase at time 2 due to firm exit. In the DMP model, the unemployment rate gradually converges to the steady state.

Panel (g) shows the labor productivity (output per worker). In the DMP model, labor productivity shows no change because it is constant by assumption. If the coordination effects are strong, labor productivity increases at time 1, even though output decreases. At time 2, as new firms are created, labor productivity goes up even further and remains elevated until the economy returns to the steady state. If the coordination effects are weak, labor productivity increases at first but drops thereafter as output continues to fall.

Panel (h) shows the vacancy rate. If the coordination effects are strong, the vacancy rate goes up at time 1 due to firm entry. If the coordination effects are weak, the vacancy rate goes down at time 1 due to firm exit. In the DMP model, the vacancy rate goes up slightly as the economy instantly sets on recovery.

Panel (i) shows the labor market tightness. Under strong coordination effects, the labor market tightness goes up at time 1 as entrants post vacancies. Under weak coordination effects, the labor market tightness goes down at time 1 as some firms exit and other firms stop hiring. In the DMP model, the market tightness decreases due to firm exit.

Panel (j) shows the wage. Under strong coordination effects, wages increase at time 1 and continue to rise in period 2, due to increased labor productivity and the tight labor market. Under weak coordination effects, wages decrease at time 1 and continue to fall in period 2 because labor productivity is low and the labor market is slack. In the DMP model, wages decrease.

Panel (k) shows the job-finding rate. Under strong coordination effects, the job-finding rate goes up at time 1 and remains elevated until the economy returns to the steady state, due to the entry of new firms. Under weak coordination effects, the job-finding rate goes down due to a loose labor market and reduced vacancy postings. In the DMP model, the job-finding rate decreases slightly.

Panel (l) shows the vacancy-filling rate. Under strong coordination effects, the vacancy-filling rate goes down at time 1 and remains low because of competition for workers in the tight labor market. Under weak coordination effects, the vacancy-filling rate goes up and remains elevated due to the slackness of the labor market. In the DMP model, the vacancy-filling rate increases slightly.

4 Concluding Remarks

This paper explains stylized facts about the post-pandemic recovery. The model extends the search and matching theory of unemployment by adding endogenous labor demand and coordination effects. The interaction of the two assumptions creates two endogenous regimes. The two regimes arise because firm entry creates two effects. On the one hand, as firms enter, they hire new workers, and employment goes up. On the other hand, firm entry raises each firm's revenue and reduces the firm size which justifies costly entry, and firms seek to hire fewer workers. Under weak coordination effects, the firm size responds to firm entry weakly, and firm entry drives employment. Under strong coordination effects, the firm size changes more than the number of workers hired by entrants, and firm entry is related to a higher unemployment rate.

The pandemic is modeled as an increase in the job separation rate. Under weak coordination effects, the model behaves similarly to the standard business cycle when high unemployment is followed by a persistent recession, lower labor productivity, and a loose labor market. Under strong coordination effects, the shock creates favorable conditions for firm entry. The shock also reduces the average firm size. Due to the coordination effects, prices for producer goods rise. As firms enter, they post vacancies. Overall, high unemployment is followed by a quick recovery in output, an increase in labor productivity, and a tight labor market.

It must be mentioned that making quantitative assessments regarding the post-pandemic recovery is challenging. A macroeconomic model for such investigation should include multiple pandemic-specific shocks and a block with monetary and fiscal policies enacted in response to the pandemic. The purpose of this paper is to explain the stylized facts at a qualitative level, and calibration is used merely to discipline the parameters of the model. A quantitative investigation is left for future research.

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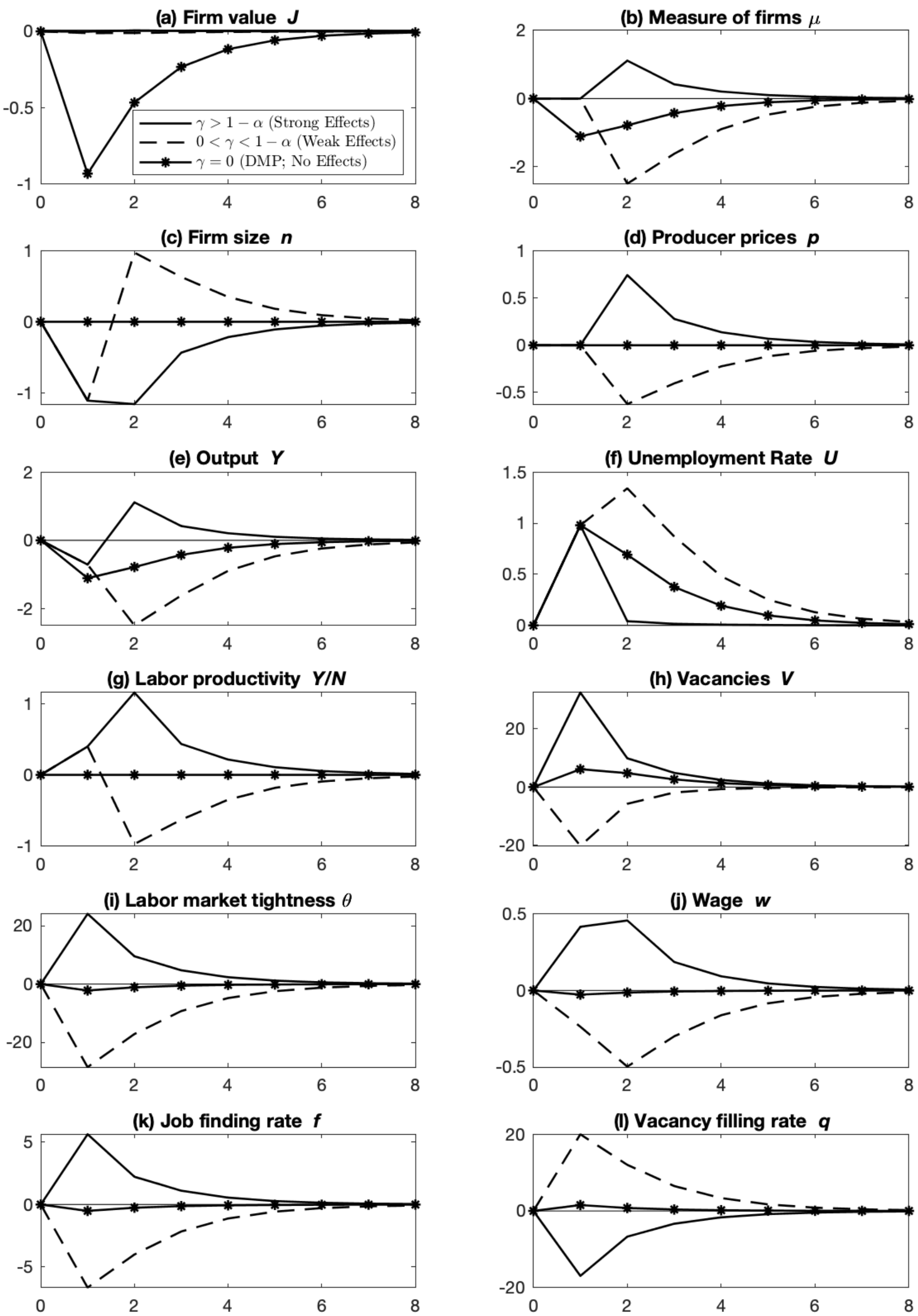

Figure 3: Impulse Response Functions to a Job Separation Shock

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