Scientific Background on the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 2010

MARKETS WITH SEARCH FRICTIONS

compiled by the Economic Sciences Prize Committee of the Royal Swedish Academy of Sciences

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1 Introduction

Most real-world transactions involve various forms of impediments to trade, or "frictions". Buyers may have trouble finding the goods they are looking for and sellers may not be able to find buyers for the goods they have to offer. These frictions can take many forms and may have many sources, including worker and firm heterogeneity, imperfect information, and costs of transportation. How are market outcomes influenced by such frictions? That is, how should we expect prices to form and—given that markets will not clear at all points in time—how are quantities determined? Do these frictions motivate government intervention? These questions are perhaps particularly pertinent in the labor market where costly and time-consuming transactions are pervasive and where the quantity determination may result in unemployment: some workers will not find job openings or their applications will be turned down in favor of other workers.

This year's Prize is awarded for fundamental contributions to search and matching theory. This theory offers a framework for studying frictions in real-world transactions and has led to new insights into the workings of markets. The development of equilibrium models featuring search and matching started in the early 1970s and has subsequently developed into a very large literature. The Prize is granted for the closely related contributions made by Peter Diamond, Dale Mortensen, and Christopher Pissarides. These contributions include the analysis of price dispersion and efficiency in economies with search and matching frictions as well as the development of what has come to be known as the modern search and matching theory of unemployment.

The research of Diamond, Mortensen and Pissarides focuses on specific frictions due to costly search and pairwise matching, i.e., the explicit difficulties buyers and sellers have in locating each other, thereby resulting in failure of markets to clear at all points in time. Buyers and sellers face costs in their attempts to locate each other ("search") and meet pairwise when they come into contact ("matching"). In contrast, standard market descriptions involve a large number of participants who trade at the same time. Access to this marketplace and all the relevant information about it is costlessly available to all economic agents; in particular, all traders would trade at the same market price. One of the main issues, therefore, is how price formation works in a market with search frictions. In particular, how much price dispersion will be observed, and how large are the deviations from competitive pricing?

Peter Diamond addressed these questions in an important paper from 1971, where he showed, first, that the mere presence of costly search and matching frictions does not suffice to generate equilibrium price dispersion. Second, and more strikingly, Diamond found that even a minute search cost moves the equilibrium price very far from the competitive price: he showed that the only equilibrium outcome is the monopoly price. This surprising finding has been labeled the "Diamond paradox" and generated much follow-up research.

Another important issue in search markets is whether there is too much or too little search, i.e., whether or not the markets deliver efficient outcomes. Since there will be unexecuted trade and unemployed resources—buyers who have not managed to locate sellers, and vice versa—the outcome might be regarded as necessarily inefficient. However, the appropriate comparison is not with an economy without frictions. Given that the friction is a fundamental one that the economy cannot avoid, the relevant issue is whether the economy is *constrained efficient*, i.e., delivers the best outcome given this restriction. It should also be noted that aggregate welfare is not necessarily higher with more search since search is costly. Diamond, Mortensen, and Pissarides all contributed important insights into the efficiency question, with the first results appearing in the late 1970s and early 1980s (Diamond and Maskin, 1979, 1981; Diamond 1982a; Mortensen, 1982a,b; Pissarides 1984a,b). A generic result is that efficiency cannot be expected and policy interventions may therefore become desirable.

Along similar lines, Diamond argued that a search and matching environment can lead to macroeconomic unemployment problems as a result of the difficulties in coordinating trade. This argument was introduced in a highly influential paper, Diamond (1982b), where a model featuring multiple steady-state equilibria is developed. The analysis provides a rationale for "aggregate demand management" so as to steer the economy towards the best equilibrium. The key underlying this result is a search externality, whereby a searching worker does not internalize all the benefits and costs to other searchers. The model Diamond developed in this context has also become a starting point for strands of literature in applied areas such as monetary economics and housing, which feature specific kinds of exchange that are usefully studied with Diamond's search and matching model.

The research on search and matching theory thus raises general and important questions relevant for many applied contexts. However, the theory has by far had its deepest impacts within labor economics. The question of why unemployment exists and what can and should be done about it is one of the most central issues in economics. Labor markets do not appear to "clear": there are jobless workers who search for work (unemployment) and firms that look for workers (vacancies). It has proven to be a difficult challenge to formulate a fully specified equilibrium model that generates both unemployment and vacancies. The research by Peter Diamond, Dale Mortensen and Christopher Pissarides has fundamentally influenced our views on the determinants of unemployment and, more generally, on the workings of labor markets. A key contribution is the development of a new framework for analyzing labor markets for both positive and normative purposes in a dynamic general equilibrium setting. The resulting class of models has become known as the Diamond-Mortensen-Pissarides model (or DMP model). This canonical model originated in the first search-matching insights from the 1970s although the crucial developments occurred later on. Especially important contributions were Mortensen and Pissarides (1994) and Pissarides (1985). The DMP model allows us to consider simultaneously (i) how workers and firms jointly decide whether to match or to keep searching; (ii) in case of a continued match, how the benefits from the match are split into a wage for the worker and a profit for the firm; (iii) firm entry, i.e., firms' decisions to "create jobs"; and (iv) how the match of a worker and a firm might develop over time, possibly leading to agreed-upon separation.

The resulting models and their further developments were quite rich and the applied research on labor markets, both theoretical and empirical, has flourished. Theoretical work has included policy analysis, both positive and normative. It was now straightforward to examine the effects of policies concerning hiring costs, firing costs, minimum wage laws, taxes, unemployment benefits, etc. on unemployment and economic welfare. Empirical work has consisted of systematic ways of evaluating the search and matching model using aggregate data on vacancies and unemployment, including the development of data bases and analyses of labor market flows, i.e., flows of workers between different labor-market activities as well as job creation and job destruction flows.

The DMP model has also been used to analyze how aggregate shocks are transmitted to the labor market and lead to cyclical fluctuations in unemployment, vacancies, and employment flows. The first step towards a coherent search-theoretical analysis of the dynamics of unemployment, vacancies and real wages was taken by Pissarides (1985).

Applications of search and matching theory extend well beyond labor markets. The theory has been used to study issues in consumer theory, monetary theory, industrial organization, public economics, financial economics, housing economics, urban economics and family economics.

2 General aspects of search and matching markets

The broad theoretical work on search and matching addresses three fundamental questions. The first is price dispersion; i.e., whether the law of one price should be expected to hold in markets with frictions. A central result here is the Diamond paradox and the subsequent attempts to resolve it. The second issue concerns efficiency, which began to be addressed in the late 1970s and into the next decade. The third question focuses on the possibility of coordination failures based on the stylized model in Diamond (1982b).

2.1 Price formation

The first strand of models with explicit search activity had an entirely microeconomic focus and examined workers' or consumers' optimal search behavior under imperfect information about wages or prices. Important early contributions to this microeconomic literature include McCall (1970) and Mortensen (1970a,b). These models generated new results regarding the determinants of search activity and, in particular, the duration of unemployment. The problem addressed in the prototype microeconomic job search model concerns the optimal rule for accepting job offers. The unemployed worker searching for employment is portrayed as unaware of wage offers available at single firms but aware of the distribution of wage offers across firms. The worker is then envisioned as sampling wage offers sequentially and attempting to maximize the expected present value of future income. Optimal search behavior involves a *reservation wage*, at which the worker is indifferent between accepting a job and remaining unemployed. The reservation wage is thus set so as to equate the value of unemployment, whose immediate return is any unemployment benefit the worker receives, to the present discounted value of future wage incomes from this job, which involves the likelihood of keeping the job, the interest rate by which the future earnings are discounted, and any expected wage movements on the job.

A fundamental question left unanswered in the early micro literature was whether the postulated distribution of prices, or wages, could be rationalized as an equilibrium outcome.

Diamond's (1971) article "A Model of Price Adjustment" established what came to be known as the *Diamond paradox.* He demonstrated, surprisingly, that under rather general conditions in an environment where buyers and sellers search for each other, and where the sellers set, i.e., commit to, prices in advance of meeting customers, the single monopoly price would prevail. Diamond argued that, even with very minor search costs and with a large number of sellers, a search and matching environment would deliver a rather large departure from the outcome under perfect competition (which would prevail if the search costs were zero). Thus, a small search friction can have a large effect on price outcomes, and it would not lead to any price dispersion at all.

A heuristic explanation of Diamond's argument is as follows. Suppose there are many identical buyers, each in search of one unit of a good, and that each consumer is willing to buy the good provided it costs no more than p^*. Suppose also that there are many identical sellers, who each commit to a price at the beginning of the game. The buyers are perfectly informed about the price distribution, but at each point in time a buyer only knows the price asked by a particular seller. Each buyer must then decide whether to be satisfied with this price or search more to learn the price of one additional seller (sequential search). This search, however, only occurs at a cost, which is assumed to be fixed. It is easy to see that optimal search policy in this context involves a cutoff price $\underline{p}$: the buyer buys the good as soon as she encounters a price at or below $\underline{p}$. The precise level of this cutoff price depends on the parameters of the model, such as the fixed search cost, and on the endogenous price distribution. Given that all consumers have identical search costs and face the same price distribution, it must then follow that they have the same cutoff price. This immediately implies that all the sellers will charge $\underline{p}$. However, if there is no dispersion in prices, it cannot be optimal to learn more than one price. Thus, the unique equilibrium is one in which all sellers charge the highest price buyers are willing to pay, i.e., p^*, the "monopoly price". Put differently, no $\underline{p}$ below p^* can be an equilibrium, since any given firm would deviate and choose a price ever so slightly higher than $\underline{p}$, by an amount small enough that it would not be worthwhile for any consumer to search for another firm. This logic works no matter how small the search cost is, as long as it is positive.

Diamond's surprising result inspired subsequent research on the existence of price and wage dispersion in search equilibrium where firms set prices (wages) optimally. Some authors, for example Albrecht and Axell (1984), developed models where some heterogeneity across workers and/or firms prevailed *ex ante* and were able to show how wage dispersion emerged as an equilibrium outcome. Other authors maintained the assumption of *ex ante* identical agents but considered alternatives to sequential search. An important contribution in this genre is Burdett and Judd (1983), who relaxed the assumption of sequential search and were able to prove that price dispersion may exist in equilibrium.

A different resolution of the Diamond paradox was offered in a paper by Burdett and Mortensen (1998). They developed a model with monopsonistic wage competition in an economy with search frictions and were able to solve explicitly for the equilibrium wage distribution. Workers are identical *ex ante* but individual heterogeneity arises *ex post* as workers become employed or unemployed. A key innovation was to allow for on-the-job search and recognize that reservation wages among employed and unemployed searchers generally differ. Reservation wage heterogeneity creates a tradeoff for firms between "volume" and "margin": high-wage firms are able to attract and retain more workers than low-wage firms are, but the rent per worker that high-wage firms can extract is relatively low. As in traditional models of monopsony, an appropriately set minimum wage can increase employment and welfare.

The literature on wage dispersion is nicely summarized in the recent book by Mortensen (2005). One strand of arguments in the literature on wage dispersion suggests that models with quantitatively large wage dispersion require that workers can search for other jobs while employed; see, e.g., Burdett (1978) for a partial-equilibrium analysis, Postel-Vinay and Robin (2002) for an equilibrium model, and Hornstein et al. (2007) for a quantitative comparison of models with and without on-the-job search.

2.2 Efficiency

Frictional markets involve search externalities that may not be internalized by agents. Consider a model where the unemployed worker determines how intensely to search for jobs. An increase in search effort implies a higher individual probability of becoming employed. However, there are two externalities which are not taken into account by the individual worker. On the one hand, by searching harder, the individual worker makes other unemployed workers worse off by reducing their job finding rates ("congestion externality"). On the other hand, by searching harder, the worker makes employers better off by increasing the rate at which they can fill their vacancies ("thick market externality"). Congestion and thick market externalities are common in search and matching models and it is *a priori* unclear whether decentralized decisions on search and wage setting will internalize them.

In a series of contributions, Diamond examined the efficiency properties of markets with frictions (Diamond and Maskin, 1979, 1981; Diamond, 1982a). Building on an earlier paper by Mortensen (1978) on efficient labor turnover, Diamond and Maskin (economics laureate in 2007) developed a model where individuals meet pairwise and negotiate contracts to carry out projects (Diamond and Maskin, 1979). The quality of the match is stochastic and matched individuals have the option to keep searching (at a cost) for better matches. A unilateral separation ("breach of contract") occurs when a partner has found a better match. The authors studied alternative compensation rules for such breaches of contract and examined how efficiency is related to the properties of the meeting technology, i.e., the matching function. In general, the compensation rules under study do not result in efficient outcomes.

Diamond (1982a) considers a labor market with search on both sides of the market albeit with a fixed number of traders. Contacts between traders – unemployed workers and firms with vacancies – are governed by a matching function and wages are determined through Nash bargaining. The paper identifies search externalities and is a precursor to more recent work on congestion and thick market externalities.

Other important contributions in this area include Mortensen (1982a,b) and Pissarides (1984a,b). Mortensen (1982a) specifies an explicit matching technology and treats the agents' search efforts as endogenous. An efficient outcome is shown to require that the match surplus should be completely allocated to the "match maker", i.e., the agent who initiated the contact. However, there is no mechanism to achieve that optimum; the equilibrium is thus generically inefficient. Mortensen (1982b) studies dynamic games, including a patent race and a matching problem, where actions taken by a single agent affect future outcomes for other agents. The main result is similar to Mortensen (1982a): efficiency requires that the agent who initiated an event should obtain the whole surplus, less a compensation paid to agents who are adversely affected. The result is sometimes referred to as the "Mortensen principle".

Pissarides (1984a) considers an economy with endogenous search intensities on both sides of the market and shows that search intensities are generally too low and equilibrium unemployment too high. Pissarides (1984b) analyzes the efficiency properties of a search economy with stochastic match productivity and finds that there can be too little or too much job rejection.

Pissarides argues that too little job rejection is the most plausible outcome, a result that may suggest a role for unemployment benefits so as to encourage more rejections of low-productivity matches.

These studies on efficiency by Diamond, Mortensen and Pissarides are forerunners to the comprehensive treatment of search externalities in matching models provided by Hosios (1990). The so-called Hosios condition states that the equilibrium outcome is constrained efficient if the elasticity of matching with respect to unemployment is equal to the worker's relative bargaining power.[1] With Nash bargaining over wages, there is no reason why the Hosios condition should apply. Recent work on efficiency properties of search equilibria has considered alternatives to Nash bargaining. One strand of literature—competitive search equilibrium theory—has shown how the Hosios condition can arise endogenously; see, e.g., Moen (1997). In one version of these models, firms post wages so as to attract more applicants. Job seekers allocate themselves across firms, while recognizing that a higher offered wage is associated with a lower probability of getting hired since a higher wage leads to a longer queue of seekers. In equilibrium, workers are indifferent about which firm to consider.

A related strand of the search literature begins with Lucas and Prescott (1974), who develop an "island model" of search. On each island, markets are competitive (with many firms competing for many workers) and there are no search costs, but workers may search among islands and be imperfectly informed about conditions on specific islands. As formulated, these models do not feature any externalities either and decentralized equilibria are efficient.

2.3 Coordination failures

In Diamond (1982b), it is argued that search externalities can even generate macroeconomic coordination problems. In order to make a comprehensive logical argument, Diamond constructed an abstract model that allowed for careful examination of these issues. Variants and further developments of this model have had a large impact in several areas of economics, not only for the study of coordination problems but also as a prototype way of studying equilibria with search and matching.

[1] Using a common functional form for the matching function, the relevant elasticity, denoted λ, is constant. In terms of the notation of the labor-market model in Section 3 below, the matching function can be written as $h(u, v) = Au^{\lambda}v^{1-\lambda}$, where u and v denote unemployment and vacancies. The Hosios condition says that $\lambda = \beta$, where β is a measure of the worker's relative bargaining power.

Consider a continuum of risk-neutral agents who derive utility from consuming an indivisible good and who discount utility at rate r; time is continuous, and the flow utility of consuming a good is y. Consumers need to trade: they each produce a good, but they do not consume the good they produce and therefore need to find a trading partner in order to exchange goods. For simplicity, Diamond assumes that a consumer is willing to consume any good other than his own. Production of goods occurs randomly and with a random cost structure. The opportunity to produce a good arrives according to a Poisson process at a flow probability rate p. When a production possibility appears, the cost of production is c, with the cost drawn from a distribution function $G(c)$. The consumer can then choose to produce or not depending on (i) how costly it is and (ii) the value of being endowed with a good that can be used for trade, which depends on how easy it is to encounter other consumers endowed with goods. Thus, the production-consumption structure assumed here is an abstract way of capturing gains from bilateral trade; though expressed a very particular way in the model, the idea and applicability of the argument seem quite general.

Bilateral meetings, however, do not occur without frictions in Diamond's model. Let the number of consumers endowed with a good, and thus searching for trading partners, be denoted s (for "searchers"). We focus on the case where the economy is in a steady state, so that s is constant. Let the flow probability of meeting a trading partner be $b(s)$, where $b(0) = 0$ and $b'(s) > 0$. The greater the number of agents searching for partners, the higher is the probability of finding one for any given agent.

The pool of searchers is diminished at each point in time by the number of traders who find partners and thus can consume, $sb(s)$. The pool is increased by the number of agents who have a production opportunity and who decide to produce: $(1 - s)pG(c^*)$, i.e., the number of non-searchers times the probability of a production opportunity times the probability that the production cost is below the cutoff cost, c^*. Flow equilibrium implies:

$$sb(s) = (1 - s)pG(c^*). \tag{1}$$

The cutoff cost is to be determined in equilibrium. Production opportunities are accepted for $c \leq c^*$ and rejected for $c > c^*$. To determine the cutoff cost, consider the flow utility of a searching consumer which is given as

$$rV_s = b(s)\left[y - (V_s - V_n)\right], \tag{2}$$

where V_s is the expected lifetime utility of a searching agent and V_n the expected lifetime utility of an agent who does not search. The searching agent meets a trading partner at the rate $b(s)$, consumes y and switches from searcher to non-searcher, thereby experiencing a loss in lifetime utility given by $V_s - V_n$. The flow utility of a non-trader reads

$$rV_n = p \max_{c^*} \int_0^{c^*} (-c + V_s - V_n) dG(c). \tag{3}$$

The non-searcher finds a production opportunity at the rate p and decides whether or not to pay the cost c, thereby experiencing a capital gain of $V_s - V_n$.

The steady state of the model is straightforward to analyze. Clearly, it must be that the cutoff cost satisfies $c^* = V_s - V_n$. It is thus possible to subtract (3) from (2) to obtain

$$rc^* = b(s)(y - c^*) + p \int_0^{c^*} c dG(c) - c^* pG(c^*). \tag{4}$$

Equation (4) and the steady-state condition given by (1) determine c^* and s. The equations can be depicted as two positively sloped relationships in the (c^*, s) space. In general, multiple equilibria are possible and equilibria involving a higher level of economic activity yield higher welfare. Thus, there is potentially a role for "demand management", i.e., for government policy inducing higher activity so that the economy could move from a bad to a good steady state.

Literally, a proof that a good steady state is better than a bad steady state is not a proof of inefficiency. The move from a bad steady state to a good steady state would require a transition period whereby agents would first start producing only to be able to trade later. Initially it would be hard to find trading partners since there are very few of them due to the low level of production. In a later paper, Diamond and Fudenberg (1989) analyzed the model from this perspective and indeed established inefficiency as well as entirely "expectations-driven" equilibrium multiplicity. They also demonstrated that this economy could feature business-cycle-like fluctuations in output without fluctuations in the fundamental parameters.

A key ingredient—subject to much discussion and empirical evaluation—in Diamond's setting is the assumption that $b(s)$ is increasing: the larger the number of traders in the market, the higher the meeting rates. That is, the more traders there are, the lower are the search frictions. This assumption, emphasizing the importance of scale, is usually referred to as one of "increasing returns to scale". It is an open question in any given trading context whether this assumption is appropriate. For labor markets, many argue that constant returns—in which case multiple steady states cannot coexist—describe reality better (see, e.g., Petrongolo and Pissarides, 2001). The model setup has also been used in other contexts, see e.g., Duffie et al. (2005) for an application to financial markets.

Diamond's (1982b) article is often viewed as defining a new approach, based on a careful analysis using microeconomic foundations, to analyzing some of the central themes of Keynes's business-cycle theory.[2] Coordination problems were of central importance in Keynes's writings; they can be viewed as a way of allowing for "sentiments" to influence the economy, such as Keynes's well-known parable of the "animal spirits" of investors. If investors sense that other investors will be active and produce, they produce too, thereby leading to high economic activity. But another equilibrium in the same economy involves low activity.

3 Equilibrium unemployment

Unemployment suggests "missing opportunities" from a societal perspective and potential inefficiency of market outcomes. Through a long series of systematic and partly overlapping contributions, Diamond, Mortensen and Pissarides have built a foundation for the analysis of labor markets based on search and matching frictions. This work, which began with Mortensen (1970a,b), has fundamentally influenced the way economists and policymakers approach the subject of unemployment. Their canonical model—the DMP model—has more broadly become a cornerstone of macroeconomic analysis of the labor market. Key contributions are Diamond (1981, 1982a,b), Mortensen (1982a,b), Pissarides (1979, 1984a,b, 1985), and Mortensen and Pissarides (1994). Pissarides's influential monograph (1990/2000) provides synthesis and extensions.[3]

The DMP model is a theoretical framework with a common core and a range of specific models that deal with particular issues and invoke alternative assumptions. Wages are usually determined via bargaining between the worker and the firm. Frictions in the market imply that there are rents to be shared once a worker and a firm have established contact. Rents are typ-

[2] Diamond's Wicksell lectures (Diamond, 1984) includes a broad discussion of the search equilibrium approach to the microfoundations of macroeconomics.

[3] Mortensen and Pissarides (1999b,c) review the search and matching model with applications to labor economics and macroeconomics. A recent comprehensive survey of search models of the labor market is provided by Rogerson et al. (2005).

ically shared through the Nash solution, but the basic model is compatible with other wage-setting rules.

An important concept in the DMP model is the so-called matching function that relates the flow of new hires to the two key inputs in the matching process: the number of unemployed job searchers and the number of job vacancies. This concept has allowed researchers to incorporate search frictions into macro models without having to specify the complex details of those frictions (such as geographical or informational detail).

3.1 A benchmark model

The benchmark labor-market model that emerged from the work of Diamond, Mortensen and Pissarides can be described in a relatively compact way. In the following, a simple version of the setup developed in Pissarides (1985) is described. This setup, which does not address wage dispersion, can perhaps be viewed as the canonical equilibrium model of search unemployment. Albeit simple, the model is flexible enough to be useful for both confronting data and analyzing policy issues.

3.1.1 Labor-market flows

Consider a labor market in a steady state with a fixed number of labor force participants, L, who are either employed or unemployed. Time is continuous and agents have infinite time horizons. Jobs are destroyed at the exogenous rate ϕ; all employed workers thus lose their jobs and enter unemployment at the same rate. Unemployed workers enter employment at the rate α which is endogenously determined. Frictions in the labor market are summarized by a matching function of the form $H = h(uL, vL)$, where uL is the number of unemployed workers and vL the number of job vacancies. The matching function is taken as increasing in both arguments, concave and exhibiting constant returns to scale. Unemployed workers find jobs at the rate $\alpha = h(uL, vL)/uL = h(1, v/u) = \alpha(\theta)$, where $\theta \equiv v/u$ is a measure of labor market tightness. Firms fill vacancies at the rate $q = h(uL, vL)/vL = h(u/v, 1) = q(\theta)$. Obviously, $\alpha'(\theta) > 0$, $q'(\theta) < 0$ and $\alpha(\theta) = \theta q(\theta)$. The tighter the labor market, the easier it is for workers to find a job, and the more difficult for firms to fill a vacancy.

A steady state entails "equilibrium" in the labor market in the sense that the unemployment rate is unchanging over time. This occurs when the inflow from employment into unemployment, $\phi(1-u)L$, equals the outflow from unemployment to employment, $\alpha(\theta)uL$. The steady-state unemployment

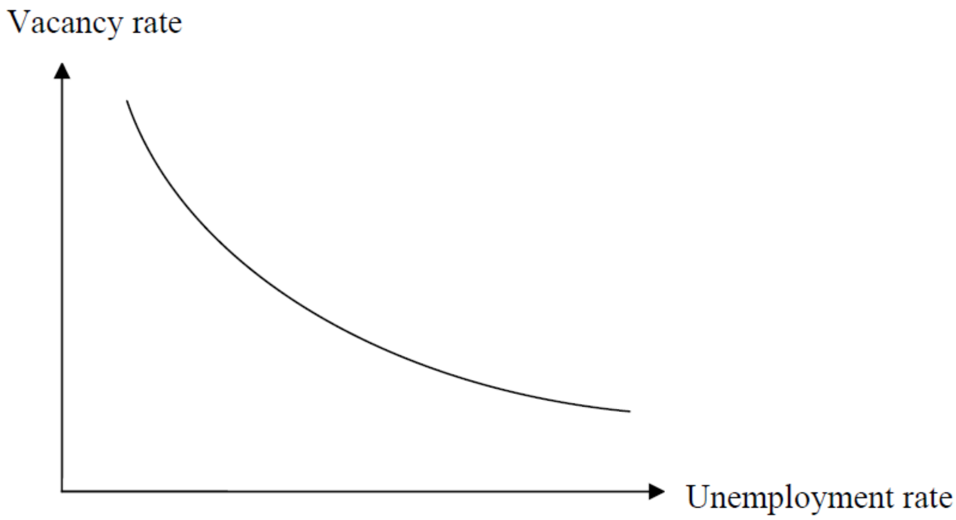

Figure 1: The Beveridge curve

rate is thus given as:

$$u = \frac{\phi}{\phi + \alpha(\theta)}. \tag{5}$$

Since $\theta \equiv v/u$, this equation also implies a negative relationship between unemployment and vacancies known as the Beveridge curve, after the British economist William Beveridge (1879–1963). It is depicted in Figure 1.

A deterioration of matching efficiency, i.e., a decline in job finding given a certain level of tightness, involves an outward shift of the Beveridge curve in the (u, v) space. An increase in the job destruction rate, possibly induced by faster sectoral reallocation of jobs, is also associated with an outward shift of the Beveridge curve. On the other hand, since other model parameters, such as the productivity of a match between worker and employer (due to technology or aggregate-demand factors), do not appear in this relation, movements in these parameters imply movements along the curve. These differences between model parameters allow us to gain insights into which fundamental factors are the likely determinants of u and v.[4]

[4] Equation (5) is a steady-state relation, and thus it is not immediate that it can be used to analyze time-series data. However, if the adjustments to steady state are rather

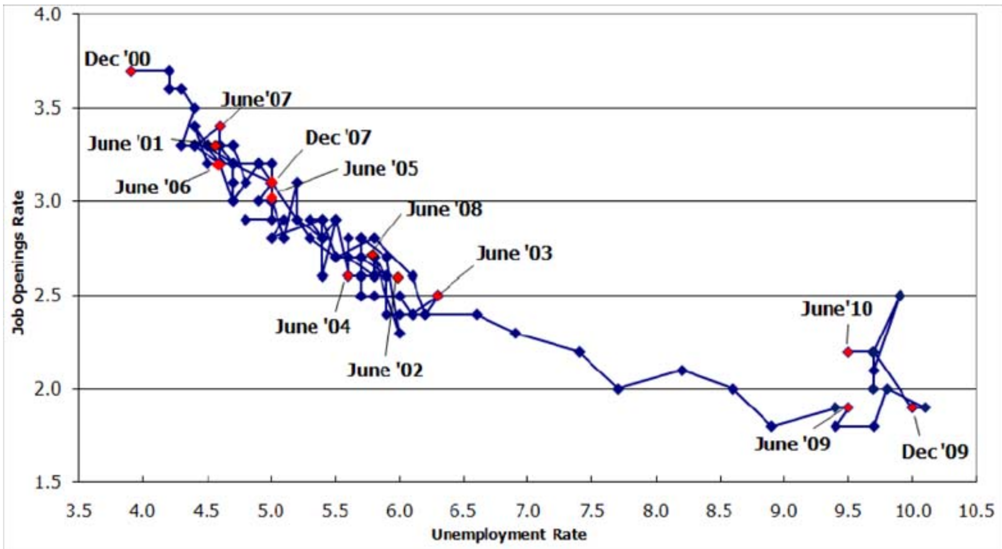

Figure 2: The U.S Beveridge curve since 2000

U.S. monthly data on unemployment and vacancies since 2000 are depicted in Figure 2.[5]The movements in u and v indicate a strong negative relationship, with little evidence of strong shifts for most of the period, thus suggesting that movements in productivity/demand account for most of the aggregate fluctuations in the labor market. During the current crisis, a marked outward shift has been observed. The reasons for this shift are not yet well understood.

3.1.2 Workers

The benchmark model features exogenous search effort and workers can only influence unemployment through their impact on wage setting. Workers care about their expected present values of incomes and recognize that these values depend on labor market transition rates as well as wages while employed

quick, the equation is a good approximation also over shorter time horizons.

[5]Source: U.S. Bureau of Labor Statistics, Job Openings and Labor Turnover Survey Highlights June 2010. August 11, 2010. The job openings rate (vacancy rate) is the number of openings divided by (employment plus job openings). The unemployment rate is unemployment divided by the labor force.

and unemployment benefits while unemployed. Let U denote the expected present value of income of an unemployed worker and W the corresponding present value of an employed worker. With an infinite time horizon and continuous time, these value functions can be written as:

$$rU = b + \alpha(\theta)(W - U) \quad (6)$$
$$rW = w + \phi(U - W) \quad (7)$$

where r is the discount rate, b is unemployment compensation (or the value of leisure or home production during unemployment), and w is the wage. Since we consider a steady state here, U and W are constant. The flow value of unemployment, rU, involves an instantaneous income b as well as the prospect of moving from unemployment to employment; this happens at the rate $\alpha(\theta)$ and involves a "capital gain" of $W - U$. The flow value of employment, rW, includes instantaneous wage income w and the risk ϕ of a job loss and the associated "capital loss" of $U - W$. From (6) and (7) one can solve for rU and rW as functions of b, w, r, $\alpha(\theta)$ and ϕ.

3.1.3 Firms

Jobs are created by firms that decide to open new positions. Job creation involves some costs and firms care about the expected present value of profits, net of hiring costs. Assume for simplicity that firms are "small" in the sense that each firm has only one job that is either vacant or occupied by a worker. There is a flow cost, k, associated with a vacancy. Let V denote that expected present value of having a vacancy and J the corresponding value of having a job occupied by a worker. A vacancy is filled at the rate $q(\theta)$, whereas an occupied job is destroyed at the rate ϕ. The value functions can thus be written as:

$$rV = -k + q(\theta)(J - V) \quad (8)$$
$$rJ = y - w + \phi(V - J) \quad (9)$$

where y is output per worker, which is taken as exogenous. The flow value of a vacancy, rV, involves an immediate cost k as well as the prospect of finding a worker and thereby turning the vacancy into an occupied job. The flow value of a filled job, rJ, involves the instantaneous profit $y - w$ but also a risk of job destruction.

Free entry of vacancies implies $V = 0$ in equilibrium: firms open vacancies as long as it is profitable to do so. By imposing the free-entry condition on eqs. (8) and (9), one obtains the key demand-side relationship of the model:

$$y - w = \frac{(r+\phi)k}{q(\theta)}. \tag{10}$$

This free-entry condition implies a negative relationship between the wage and labor market tightness. The tighter the labor market, the more costly it is to recruit new workers. This has to be offset by lower wages so as to maintain zero profits. Note that $y > w$ must hold because of hiring costs, $k > 0$. In equilibrium, the excess of the marginal product of labor over the wage cost is equal to the expected capitalized value of the vacancy cost. The incentives to create vacancies are reduced by a higher real interest rate, a higher job destruction rate and a higher vacancy cost. Vacancy creation is encouraged by improved matching efficiency that exogenously increases the rate at which the firm meets job searchers.

3.1.4 Wage bargaining

Since the labor market is characterized by frictions and bilateral meetings, the standard wage determination mechanism does not come into play. So how are wages determined? The main approach that has been used in the literature assumes that there is bargaining between the employer and the worker. So suppose that wages are set through individual worker-firm bargains and that the Nash solution applies, i.e.,

$$\max_{w} \Omega = [W(w) - U]^{\beta} [J(w) - V]^{1-\beta},$$

where β is a measure of the worker's relative bargaining power, $\beta \in (0, 1)$. $W(w)$ and $J(w)$ represent present values associated with a particular wage w in this bilateral bargain (to be distinguished from the wage used in other matches), i.e.,

$$\begin{aligned} rW(w) &= w + \phi [U - W(w)], \\ rJ(w) &= y + \phi [V - J(w)]. \end{aligned}$$

The value of unemployment is independent of w and is obtained from eqs. (6) and (7). Note that the threat points in the Nash bargain are taken to be

U and V, i.e., what the worker and the firm would receive upon separation from each other.

The outcome of this maximization is a surplus-sharing rule of the form:

$$W(w) - U = \beta \left[W(w) - U + J(w) - V \right]. \tag{11}$$

The wage is set so as to give the worker a fraction β of the total surplus from a wage agreement. Eq. (11) can be rewritten in several ways so as to yield a wage equation, i.e., the bargained wage as a function of labor market tightness and the parameters of the problem. A useful partial-equilibrium wage equation expresses the wage as a weighted average of labor productivity and the flow value of unemployment:[6]

$$w = \beta y + (1 - \beta) rU. \tag{12}$$

It is possible to go one step further to obtain the following:[7]

$$w = (1 - \beta) b + \beta (y + k\theta). \tag{13}$$

This expression has the intuitive property that the bargained wage is an increasing function of unemployment benefits, labor productivity and labor market tightness.

3.1.5 Equilibrium

The overall steady-state equilibrium is now characterized by eqs. (5), (10) and (13). Eqs. (10) and (13) determine w and θ and the unemployment rate follows from (5). The vacancy rate is obtained by using the fact that $v = u\theta$. The equilibrium unemployment rate is determined by b, y, k, β, r, ϕ as well as by the parameters of the matching function. It is possible, by variable substitution, to reduce the set of equations to one equation in one unknown: labor-market tightness.

3.1.6 Comparative statics, policy analysis, and model evaluation

Given that the model can be analyzed in such a simple way, comparative static analysis is straightforward. Consider for example an increase in un-

[6] Use $rW(w) = w + \phi [U - W(w)]$ and $rJ(w) = y - w + \phi [V - J(w)]$, substitute these expressions into (11) and impose the free-entry condition $V = 0$.

[7] Impose free entry in (8) and obtain $J = k/q(\theta)$. Use $J = k/q(\theta)$ in (11) to obtain a relationship between $W - U$ and $k/q(\theta)$. Substitute the expression into (6) to eliminate $W - U$ and substitute the resulting expression for rU back into (12).

employment benefits. This raises the value of unemployment and reduces the worker's gain from a wage agreement; the resulting increase in wage pressure leads to a decline in job creation, higher unemployment and higher real wages. A higher real interest rate has an adverse impact on job creation which leads to fewer vacancies, higher unemployment and lower real wages. It also easy to verify that unemployment increases if there is an increase in the vacancy cost, the job destruction rate, or the worker's relative bargaining power. The matching function enters via two routes: $\alpha(\theta)$ in eq. (5)—the Beveridge curve—and $q(\theta)$ in eq. (10), the free-entry condition. Improvements in the matching technology reduce unemployment directly (holding the number of vacancies constant) as well as indirectly (by effectively reducing hiring costs and thereby encouraging job creation) and real wages increase.

The impact of productivity on unemployment is intriguing. In the benchmark model as spelled out above, a higher level of productivity leads to lower unemployment; the positive impact on job creation dominates the offsetting effect arising from higher wage pressure. Arguably, this result is reasonable for the short run but not for the long run, since the *level* of productivity is a positively trended variable whereas unemployment does not appear to have a trend over a long enough period in time. A model able to replicate the stylized facts of balanced growth should thus feature increasing real wages but constant unemployment. Two slight modifications of the benchmark model are sufficient for achieving that goal. The specifications of vacancy costs and unemployment benefits, possibly including the value of home production, are crucial. Suppose that unemployment benefits are "indexed" to real wages (or productivity) and the hiring cost grows in tandem with real wages (or productivity). Then real wages will be responsive to general productivity improvements and the model would, in fact, yield predictions consistent with stylized balanced growth facts.[8]

The model provides a useful framework for analyses of various policy issues. The effects of hiring and firing costs are two pertinent examples. The impact of firing costs depends on whether the costs involve transfers to workers who are laid off or appear as "red tape" costs perhaps associated with stringent employment protection rules. Layoff costs that take the form

[8]The modifications of the benchmark model can be rationalized in various ways. Unemployment benefits are in practice typically indexed to wages and recruitment activities are labor intensive activities. More generally, the worker's imputed income during unemployment can be regarded as proportional to his permanent income, i.e., U. See Pissarides (2000), chapter 3, for a discussion of some of the issues involved.

of severance pay to laid-off workers do not alter the total surplus of a match and will not affect job creation and unemployment. Red tape costs reduce the surplus of a match and lead to lower job creation.

There is also a large literature that assesses the model quantitatively, using a variety of evaluation methods and different data sets. The development of search and matching theory has led to a large empirical literature. The early microeconomic models of job search initiated new data collection efforts focusing on individual labor market transitions, in particular transitions from unemployment to employment. The more recent macroeconomics-oriented search and matching theory has been developed in parallel with improved data availability on worker flows and job flows (see Section 3.3 below).

The microeconomic search models have stimulated numerous empirical studies of the determinants of unemployment duration. The methodological literature on econometric duration analysis has expanded substantially over the past couple of decades, a development that is to a large extent driven by the growth and impact of microeconomic search theory. The effects of unemployment benefits on individual unemployment duration constitute the most widely researched issue in this strand of literature. The early papers, dating back to the late 1970s, typically identified the impact by exploiting cross-sectional benefit variation across individuals. More recent studies have exploited information from policy reforms and quasi-experiments. The empirical studies generally suggest that more generous benefits tend to increase the duration of unemployment. A key theoretical prediction from Mortensen (1977)—that the exit rate from unemployment increases as the worker approaches benefit exhaustion—has been corroborated in a very large number of studies from many countries.

Although information about how individuals respond to benefit changes is useful, it captures only a partial equilibrium relationship since firm behavior is ignored. The equilibrium outcome will almost certainly differ quantitatively and conceivably also qualitatively from the partial equilibrium relationship. Moreover, there are many policies, such as minimum wages or employment subsidies, that cannot be analyzed within the partial equilibrium framework. These concerns have initiated a number of attempts to estimate models of equilibrium search econometrically using micro data. A seminal paper is Eckstein and Wolpin (1990), who estimated the Albrecht and Axell (1984) model. A more recent study is van den Berg and Ridder (1998), who estimated an extended version of the Burdett and Mortensen (1998) model. Mortensen (2005) includes a comprehensive discussion of wage differences in Denmark from the perspective of search and matching models. Eckstein and van den Berg (2007) provide a recent survey of this literature.

The aggregate matching function—an important tool kit in search and matching theory—has been the subject of considerable empirical research. Blanchard and Diamond (1990) examine U.S. data and find support for a stable matching process. Petrongolo and Pissarides (2001) survey the empirical literature and conclude that there is strong evidence in favor of the conventional constant returns assumption.

Empirical research on the determinants of unemployment has often used panel data for OECD countries in order to study the role of policies and labor market institutions. These studies are in general theoretically eclectic, drawing informally on search and matching theory as well as on models associated with Layard, Nickell and Jackman that do not explicitly consider labor market flows (Layard et al., 1991). The studies provide fairly strong evidence that policies and institutions matter for long-run unemployment outcomes. It is typically found that policies that reduce labor market flows, such as employment protection laws, have little effect on aggregate unemployment although they do increase youth unemployment and the average duration of unemployment.

Search and matching models have been widely applied in calibration and simulation exercises, typically to shed light on specific policy issues. An example is Mortensen (1994b), who examined a variety of labor market policies using the Mortensen and Pissarides (1994) model. Another example is Mortensen and Pissarides (1999a) who extended the Mortensen and Pissarides (1994) model to account for heterogeneous labor and studied unemployment responses to skill-biased technology shocks and their interactions with labor market policies. Search-and-matching models have also been used in comparisons of unemployment outcomes between the U.S. and Europe; see Rogerson and Shimer (2010) for a discussion of this literature.

The search-and-matching model also suggests exploring data sets for firms and, in particular, data sets with information about employer-employee pairings. Reliable data sets of this kind have not been studied until rather recently; see Lentz and Mortensen (2010) for a survey of this literature, which also provides links with the field of industrial organization.

3.2 Extensions of the benchmark model

The benchmark model outlined above can be extended in many ways and numerous extensions have appeared in the literature. As regards the impact of productivity, note that a model where unemployment is invariant with respect to the *level* of productivity does not rule out that unemployment responds to changes in the *rate of growth* of productivity. The model has been extended so as to incorporate technological growth, thus allowing studies of how an exogenous change in the rate of growth affects unemployment; see e.g. Pissarides (1990/2000) and Mortensen and Pissarides (1998).

It is straightforward to introduce endogenous search effort, thereby giving the worker some direct influence over the duration of unemployment. Some authors have introduced stochastic job matchings, i.e., the idea that the productivity of a match is uncertain before a worker and a vacancy have met but is revealed once a contact is established. When uncertainty is resolved, some matches will be accepted but others will be rejected. Endogenous work hours and labor force participation are easily incorporated. The "small firm" assumption of the benchmark model can be recast as a model of a "large firm" that uses labor and capital and produces under constant returns to scale.

The first generation of DMP models focused on job creation whereas job destruction was treated as exogenous. Changes in unemployment were thus determined by changes in job finding whereas a worker's layoff risk was taken as exogenous. Mortensen and Pissarides (1994) initiated a second-generation version of the framework by allowing for endogenous job destruction and thereby also endogenous worker separations. This paper introduces stochastic productivity shocks and analyzes how firms and workers respond to these shocks. At job creation, the firm is free to choose its (irreversible) technology and profit maximization implies that new jobs are created at maximum productivity. When hit by a productivity shock, the firm determines whether it should remain in business or shut down, while recognizing the possibility of renegotiating the wage contract. Changes in exogenous variables, such as unemployment benefits or matching efficiency, influence unemployment through the impact on job creation (job finding) as well as job destruction (worker separations). Mortensen's and Pissarides's theoretical work on these matters has been nicely matched by a growing empirical literature based on new data on job creation and job destruction (see, e.g., Davis et al., 1996).

Most versions of the DMP model ignore on-the-job search and job-to-job mobility. Labor turnover is then identical to job turnover. That is, workers leave their firms only when jobs are destroyed and they find new jobs only via a spell of unemployment. In reality, however, job-to-job quitting without intervening unemployment accounts for a substantial fraction of total job separations. Contributions by Pissarides (1992, 2000) and Mortensen (1994a) show how equilibrium search models can be extended so as to incorporate on-the-job search and job-to-job movements.[9]

Recent extensions and generalizations of the DMP core include studies that examine the microeconomic foundations of the matching function (Lagos, 2000; Stevens, 2007). Others have considered alternatives to the random matching assumption of the canonical model; see, e.g., Coles and Petrongolo (2008) and Ebrahimy and Shimer (2010). Several recent papers have suggested modifications of the standard Nash bargaining assumptions so as to improve the model's ability to account for cyclical fluctuations in unemployment and vacancies (more on this below). Risk aversion in the context of equilibrium search-and-matching models has been less studied; in most relevant cases, it necessitates numerical model solution (see, e.g., Acemoglu and Shimer, 1999).

3.3 Cyclical fluctuations

The first step towards a coherent search-theoretical analysis of the dynamics of unemployment, vacancies and real wages was taken by Pissarides (1985). Pre-existing dynamic general equilibrium models of business cycles had either abstracted from unemployment or viewed unemployment as "voluntary", i.e., as an implication of workers' labor supply decisions. Given that unemployment is a key cyclical indicator, Pissarides's framework of analysis was a very important step forward in the literature on business cycles.

The core model is a slightly altered version of the benchmark model outlined previously. It thus describes an economy where vacancies and unemployed workers meet according to an aggregate matching function. Productivity is match-specific so that only some of the meetings between vacancies and workers result in actual matches, but there is also an aggregate component to productivity that varies randomly over time. Wages are determined through Nash bargaining and there is free entry of new vacancies. Vacancies, determined by firms, are fully flexible and respond instantaneously to aggregate shocks. In terms of modeling, Pissarides's treatment of vacancies constituted an innovation in this literature. Unemployment is partly predetermined since the job creation process is time consuming.

Pissarides employs the model to study the responses to unanticipated shocks to productivity and derives the cyclical correlation between unemployment and vacancies. The model also predicts that the response of unemployment to an adverse shock will be faster and sharper than the response

[9] Burdett (1978) provided the seminal paper on employee search and quit rates in a partial equilibrium setting.

to a positive shock. The reason for this asymmetry is that an adverse shock results in an immediate increase in job separations and thereby to an upward jump in the unemployment rate. A positive shock leads to a gradual fall in unemployment driven by the time-consuming hiring process.

Does the model with search and matching frictions generate aggregate fluctuations, in labor markets and in other aggregates, that are also quantitatively consistent with data? Two early studies (Merz, 1995 and Andolfatto, 1996) propose unified models essentially combining the real-business-cycle model due to Kydland and Prescott (1982) and the DMP model, with some success. Following Shimer (2005), a stream of recent papers has looked at this issue and found that the baseline model generates too little variability compared with the data. The search and matching approach to analyzing fluctuations *per se* is not necessarily at issue in this debate, but some specific details of the model are. For example, the Nash bargaining assumption for wage determination has been scrutinized and it seems as if it leads to excess real wage flexibility, and too little unemployment volatility, in response to shocks (Hall, 2005). Following Binmore et al. (1986), Hall and Milgrom (2008) suggest that the relevant threat points in the wage bargain should be payoffs during delays rather than payoffs available if the parties separate from each other. Gertler and Trigari (2009) replace continuous Nash bargaining by staggered multi-period Nash bargaining. These contributions and others indicate that the model's cyclical performance can be improved by introducing elements of wage stickiness. However, Pissarides (2009) surveys the empirical literature on wage flexibility and argues the wage stickiness is not the answer since wages in new matches are highly flexible. Another ingredient that matters for the model's cyclical properties is the value assigned to leisure (or home production) during unemployment (Hagedorn and Manovskii, 2008; Mortensen and Nagypal, 2007).

The DMP model has also been very important in allowing researchers to connect to data more focused on how jobs appear and disappear. Based on the longitudinal data first studied by Davis and Haltiwanger (1992), Cole and Rogerson (1999) specifically address the ability of the model in Mortensen and Pissarides (1994) to match the cyclical movements in job destruction and job creation rates. They find that so long as unemployment duration is long enough, the model fits the facts quite well. The research on cyclical fluctuations in labor markets is very much ongoing and, although the DMP model remains the main workhorse, alternatives will undoubtedly be explored and compared to it in the years to come.

4 Other applications of search and matching theory

Search and matching theory has also been applied to studies of issues in monetary theory, with Nobuhiro Kiyotaki and Randall Wright as the main contributors; see for example Kiyotaki and Wright (1989, 1993). This literature has examined the role of money in economies with search frictions. The central role of money as a medium of exchange is formalized in models with costly transactions. Fiat money (or commodity money) emerges endogenously in these models. The models can be used to study the welfare role of money and the possibility of equilibria with multiple currencies.

Search theory is a useful framework for studies of the housing market. In an early paper, Wheaton (1990) developed a model of the housing market with search frictions and bargained prices. In addition to a set of positive predictions, the model has the normative implication that private search decisions are suboptimal. Recent contributions to a growing literature on search in the housing market include Albrecht et al. (2007).

Search theory has been invoked to study various issues in public finance, especially concerning labor taxation and social insurance. With search frictions and decentralized wage bargaining, labor taxation will generally affect search effort as well as bargained outcomes. Standard results from competitive models may no longer hold. Bovenberg (2006) includes a comprehensive treatment of models of labor taxation in economies with search frictions or other imperfections. The search framework is also the natural framework for studies of positive and normative aspects of unemployment insurance and has been widely used for those purposes. An early contribution by Diamond (1981) shows that the presence of search externalities could motivate the introduction of unemployment compensation even though all agents are risk neutral. The model provides an efficiency argument for public intervention that makes job searchers more selective in their job acceptance decisions. The idea has been revived in recent empirical and theoretical work on unemployment insurance; see for example Acemoglu and Shimer (2000).

Duffie et al. (2005) make use of a search and matching model to study issues in financial economics. They develop a variant of the model in Diamond (1982b) and study the interaction between agents in over-the-counter markets. Search frictions affect prices and allocations, and the equilibrium outcomes are not necessarily socially efficient. A similar market microstructure approach to the study of financial markets can be found in Weill (2007).

Search theory has turned out to be a valuable tool for theoretical and empirical research in urban economics; see Zenou (2009) for a recent monograph on urban labor economics. This research introduces spatial frictions (commuting costs) and location choice into a search and matching framework. This helps to explain the determinants of urban spatial structure, the choice of transport mode and segregation.

Search theory has been applied to analyses of the marriage market by, among others, Mortensen (1988), Burdett and Coles (1997, 1999) and Shimer and Smith (2000). The marriage market has features that can be well captured by the search and matching framework. Agents (singles) need to spend time and incur costs to meet; agents typically strive for long-term relationships; and there is competition among agents. The literature has been concerned with the derivation of equilibrium outcomes with different sorting characteristics, such as assortative mating where the traits of the spouses are positively correlated.

5 Other contributions

Both Mortensen's and Pissarides's research careers have centered around search and matching theory and, in particular, building foundations for labor market models featuring unemployment. Diamond's work, however, also contains important contributions not directly related to search and matching. These contributions deserve a brief discussion here partly because they deal with frictions in markets in a broader sense.

Peter Diamond's work on frictions spans a very broad set of issues. An extreme form of friction is the case of missing markets. This type of friction naturally arises in the context of uncertainty. Here, Diamond has made seminal contributions. When economic agents face uncertainty in the form of a large number of possible states of nature, a complete market structure would require a very large number of financial assets. With such a market structure, it would then be possible to fully insure against all kinds of risk, including risks that are specific to individual firms or consumers. With access to a perfect market to insure against all kinds of risk, life would be unrealistically simple. Diamond argued that a better description of how agents have to deal with uncertainty is one where insurance possibilities are limited or even absent.

Diamond (1967) pioneered the analysis of economies where some insurance markets are missing and asked how the absence of such markets would influence allocations, economic efficiency and perhaps provide a reason for government intervention. He argued that potentially useful government policy would not be able to directly overcome the lack of insurance markets by simply introducing them. Instead, he insisted that in order to provide a fair comparison between what markets and governments can do, the scope of government policy should also be limited by the incomplete market structure. The idea that a government should be restricted by the same frictions as those faced by markets is fundamental and has profoundly influenced the subsequent literature. The treatment of efficiency in Diamond's early work is paralleled in the search and matching literature, where governments also have to "play by the rules of the frictions"; i.e., they have no way of directly overcoming the frictions. Much of that literature, including Diamond's own later work on health insurance (Diamond and Mirrlees, 1978), extends beyond his initial constrained efficiency concept by more carefully analyzing why markets are missing (such as private information).

Since Diamond's initial 1967 paper, an incomplete-markets literature has developed. This literature has examined the assumptions under which equilibria exist, are unique, and are constrained efficient. Important contributions to this literature include Stiglitz (1972), Jensen and Long (1972), Hart (1975), Grossman and Hart (1979), and Geanakoplos and Polemarchakis (1986) who demonstrated that incomplete asset markets may be inefficient in a such a way that government policy could lead to Pareto improvements. Another branch of the incomplete asset market literature develops important macroeconomic applications. Beginning with Bewley (undated), Huggett (1993), and Aiyagari (1994), general-equilibrium models have been developed where markets for idiosyncratic consumer risks are not present (but where consumers can buffer-save, as in Schechtman, 1976, and Bewley, 1977).

Diamond has also analyzed intergenerational market inefficiencies. Current and future, not-yet-born, generations are not directly connected to each other in the marketplace, and market outcomes may not be efficient under these circumstances. In perhaps his best-known work, Diamond (1965) develops an overlapping generations (OLG) model with capital accumulation using a one-sector neoclassical production technology in order to analyze how government debt policy influences market outcomes and consumer welfare. Allais (1947) had already demonstrated that debt policy in a similar OLG model may be used to increase steady state consumption and welfare. A similar result is derived in Diamond (1965). His analysis of debt and its potentially welfare-improving consequences has had profound impact on the profession. His formulation of the overlapping-generations model, which combines the Solow-Swan growth model with an overlapping-generations population structure, still constitutes the benchmark model of government debt, social security, and intergenerational redistribution.[10] In particular, it has lent itself to policy-oriented modeling with a high degree of realism; see for instance Auerbach and Kotlikoff (1987).

Finally, Diamond has also made important contributions to the more "traditional" theory of public finance. Here, the best-known contribution is the production efficiency result of Diamond and Mirrlees (1971a, 1971b). The argument here is that production efficiency should be maintained in the "second-best" allocation where by necessity—since non-distortionary taxes are not available—many other private decisions are distorted. As a result, taxes on intermediate goods should all be zero and all of the tax burden should be borne by other tax bases. Thus, production distortions cannot help mitigate other distortions and can therefore never be beneficial. The production efficiency result has direct and easily communicated implications for optimal tax systems as well as for trade policy. For example, corporate income tax rates and taxes on goods that are only used as intermediate goods (such as machine parts and construction material) should be zero. Observed real-world deviations from this result therefore cannot be motivated from an efficiency point of view.

6 Conclusions

Search and matching theory has evolved from microeconomic decision theory to the leading paradigm in macroeconomic analyses of the labor market. The theory has also proven to be eminently fruitful in many other areas. It has shed light on a host of policy issues and has initiated a vast empirical literature. The three leading contributors to search and matching theory are Peter Diamond, Dale Mortensen, and Christopher Pissarides.

Diamond, Mortensen, and Pissarides have developed search and matching theory in a number of important ways. These include (i) the literature on wage and price dispersion in search equilibrium; (ii) the literature on macroeconomic coordination problems; (iii) foundational work on constrained efficiency in search and matching markets; and (iv) and the development of the canonical Diamond-Mortensen-Pissarides model of unemployment, which has become a workhorse in macroeconomic analysis and is an important tool for policymaking.

[10] Allais (1947) used a two-sector model with particular differences in production functions across consumption and investment sectors. His analysis was less general but reached the same, key insights about the role and desirability of debt as in Diamond's 1965 paper.

References

Acemoglu, D and R Shimer (1999), Efficient Unemployment Insurance, *Journal of Political Economy* 107, 893–928.

Acemoglu, D and R Shimer (2000), Productivity Gains from Unemployment Insurance, *European Economic Review* 44, 1195–1224.

Aiyagari, S R (1994), Uninsured Idiosyncratic Risk and Aggregate Saving, *Quarterly Journal of Economics* 109, 659–684.

Albrecht, J and B Axell (1984), An Equilibrium Model of Search Unemployment, *Journal of Political Economy* 92, 824–840.

Albrecht, J, A Anderson, E Smith and S Vroman (2007), Opportunistic Matching in the Housing Market, *International Economic Review* 48, 641–664.

Allais, M (1947), *Economie et Intérét*, Imprimiere Nationale.

Andolfatto, D (1996), Business Cycles and Labor-Market Search, *American Economic Review* 86, 112–132.

Auerbach, A and L Kotlikoff (1987), *Dynamic Fiscal Policy*, Cambridge University Press.

Bewley, T (undated), Interest Bearing Money and the Equilibrium Stock of Capital, manuscript, Yale University.

Bewley, T (1977), The Permanent Income Hypothesis: A Theoretical Formulation, *Journal of Economic Theory* 16, 252–292.

Binmore, K, A Rubinstein and A Wolinsky (1986), The Nash Bargaining Solution in Economic Modeling, *Rand Journal of Economics* 17, 176–188.

Blanchard, O and P Diamond (1990), The Aggregate Matching Function, in P Diamond (ed.), *Growth, Productivity, Unemployment*, MIT Press.

Bovenberg, L (2006), Tax Policy and Labor Market Performance, in J Agell and P Birch Sorensen (eds.), *Tax Policy and Labor Market Performance*, MIT Press.

Burdett, K (1978), A Theory of Employee Search and Quit Rates, *American Economic Review* 68, 212–220.

Burdett, K and M Coles (1997), Marriage and Class, *Quarterly Journal of Economics* 112, 141–168.

Burdett, K and M Coles (1999), Long-Term Partnership Formation: Marriage and Employment, *Economic Journal* 109, F307-334.

Burdett, K and K Judd (1983), Equilibrium Price Dispersion, *Econometrica* 51, 955–969.

Burdett, K and D Mortensen (1998), Wage Differentials, Employer Size and Unemployment, *International Economic Review* 39, 257–273.

Cole, H and R Rogerson (1999), Can the Mortensen-Pissarides Matching Model Match the Business-Cycle Facts?, *International Economic Review* 40, 933–959.

Coles, M and B Petrongolo (2008), A Test Between Stock–Flow Matching and the Random Matching Approach, *International Economic Review* 49, 1113–1539.

Davis, S and J Haltiwanger (1992), Gross Job Creation, Gross Job Destruction, and Employment Reallocation, *Quarterly Journal of Economics* 107, 819–863.

Davis, S, J Haltiwanger and S Schuh (1996), *Job Creation and Job Destruction*, MIT Press.

Diamond, P (1965), National Debt in a Neoclassical Growth Model, *American Economic Review* 55, 1126–1150.

Diamond, P (1967), The Role of a Stock Market in a General Equilibrium Model with Technological Uncertainty, *American Economic Review* 57, 759–776.

Diamond, P (1971), A Model of Price Adjustment, *Journal of Economic Theory* 3, 156–168.

Diamond, P (1981), Mobility Costs, Frictional Unemployment, and Efficiency, *Journal of Political Economy* 89, 798–813.

Diamond, P (1982a), Wage Determination and Efficiency in Search Equilibrium, *Review of Economic Studies* 49, 217–227.

Diamond, P (1982b), Aggregate Demand Management in Search Equilibrium, *Journal of Political Economy* 90, 881–894.

Diamond, P (1984), *A Search-Equilibrium Approach to the Micro Foundations of Macroeconomics*, MIT Press.

Diamond, P and D Fudenberg (1989), Rational Expectations Business Cycles in Search Equilibrium, *Journal of Political Economy* 97, 606–619.

Diamond, P and E Maskin (1979), An Equilibrium Analysis of Search and Breach of Contract, I: Steady States, *Bell Journal of Economics* 10, 282–316.

Diamond, P and E Maskin (1981), An Equilibrium Analysis of Search and Breach of Contract, II: A Non-Steady State Example, *Journal of Economic Theory* 25, 165–195.

Diamond, P and J Mirrlees (1971a), Optimal Taxation and Public Production I: Production Efficiency, *American Economic Review* 61, 8–27

Diamond, P and J Mirrlees (1971b), Optimal Taxation and Public Production II: Tax Rules, *American Economic Review* 61, 261–278.

Diamond, P and J Mirrlees (1978), A Model of Social Insurance with Variable Retirement, *Journal of Public Economics* 10, 295–336.

Duffie, D, N Gârleanu and L H Pedersen (2005), Over-the-Counter Markets, *Econometrica* 73, 1815–1847.

Eckstein, Z and K Wolpin (1990), Estimating a Market Equilibrium Search Model from Panel Data on Individuals, *Econometrica* 58, 783–808.

Eckstein, Z and G van den Berg (2007), Empirical Labor Search: A Survey, *Journal of Econometrics* 136, 531–564.

Ebrahimy, E and R Shimer (2010), Stock-Flow Matching, *Journal of Economic Theory* 145, 1325–1353.

Geanakoplos, J and H Polemarchakis, (1986), Existence, Regularity, and Constrained Suboptimality of Competitive Allocations when the Asset Market is Incomplete, in W Heller, R Starr and D Starret (eds.), *Uncertainty, Information and Communication: Essays in Honor of Kenneth J. Arrow, Vol. 3,* Cambridge University Press.

Gertler, M amd A Trigari (2009), Unemployment Fluctuations with Staggered Nash Wage Bargaining, *Journal of Political Economy* 117, 38–86.

Grossman, S and O Hart (1979), A Theory of Competitive Equilibrium in Stock Market Economies, *Econometrica* 47, 293–329.

Hagedorn, M and I Manovskii (2008), The Cyclical Behavior of Equilibrium Unemployment and Vacancies Revisited, *American Economic Review* 98, 1692–1706.

Hall, R (2005), Employment Fluctuations with Equilibrium Wage Stickiness, *American Economic Review*, 95, 50–65.

Hall, R and P Milgrom (2008), The Limited Influence of Unemployment on the Wage Bargain, *American Economic Review* 98, 1653–1674.

Hart, O (1975), On the Optimality of Equilibrium when the Market Structure is Incomplete, *Journal of Economic Theory* 11, 418–443.

Hornstein, A, P Krusell and G Violante (2007), Frictional Wage Dispersion in Search Models: A Quantitative Assessment, NBER Working Paper No. 13674.

Hosios, A (1990), On the Efficiency of Matching and Related Models of Search and Unemployment, *Review of Economic Studies* 57, 279–298.

Huggett, M (1993), The Risk-Free Rate in Heterogeneous-Agent Incomplete-Insurance Economies, *Journal of Economic Dynamics and Control* 17, 953–969.

Jensen M and J Long (1972), Corporate Investment Under Uncertainty and Pareto Optimality in the Capital Markets, *Bell Journal of Economics and Management Science* 3, 151–174.

Kiyotaki, N and R Wright (1989), On Money as a Medium of Exchange, *Journal of Political Economy* 97, 927–954.

Kiyotaki, N and R Wright (1993), A Search-Theoretic Approach to Monetary Economics, *American Economic Review* 83, 63–77.

Kydland, F and E Prescott (1982), Time to Build and Aggregate Fluctuations, *Econometrica* 50, 1345–1370

Lagos, R (2000), An Alternative Approach to Search Frictions, *Journal of Political Economy* 108, 851–873.

Layard, R, S Nickell and R Jackman (1991), *Unemployment: Macroeconomic Performance and the Labour Market*, Oxford University Press.

Lentz, R and D Mortensen (2010), Labor Market Models of Worker and Firm Heterogeneity, *Annual Review of Economics* 2, 577–602.

Lucas, R and E Prescott (1974), Equilibrium Search and Unemployment, *Journal of Economic Theory* 7, 188–209.

McCall, J (1970), The Economics of Information and Job Search, *Quarterly Journal of Economics* 84, 113–126.

Merz, M (1995), Search in the Labor Market and the Real Business Cycle, *Journal of Monetary Economics*, 36, 269–300.

Moen, E (1997), Competitive Search Equilibrium, *Journal of Political Economy* 105, 385–411.

Mortensen, D (1970a), A Theory of Wage and Employment Dynamics, in E S Phelps et al., *Microeconomic Foundations of Employment and Inflation Theory*, Macmillan.

Mortensen, D (1970b), Job Search, the Duration of Unemployment and the Phillips Curve, *American Economic Review* 60, 847–862.

Mortensen, D (1977), Unemployment Insurance and Job Search Decisions, *Industrial and Labor Relations Review* 30, 505–517.

Mortensen, D (1978), Specific Capital and Labor Turnover, *Bell Journal of Economics* 9, 572–586.

Mortensen, D (1982a), The Matching Process as a Noncooperative Bargaining Game, in J McCall (ed.), *The Economics of Information and Uncertainty*, University of Chicago Press.

Mortensen, D (1982b), Property Rights and Efficiency in Mating, Racing and Related Games, *American Economic Review* 72, 968–979.

Mortensen, D (1988), Matching: Finding a Partner for Life or Otherwise, *American Journal of Sociology* 94 (Supplement), S215–S240.

Mortensen, D (1994a), The Cyclical Behavior of Job and Worker Flows, *Journal of Economic Dynamics and Control* 18, 1121–1142.

Mortensen, D (1994b), Reducing Supply-side Disincentives to Job Creation, in *Reducing Unemployment: Current Issues and Policy Options*, Federal Reserve Bank of Kansas City.

Mortensen, D (2005), *Wage Dispersion: Why Are Similar Workers Paid Differently*?, MIT Press.

Mortensen, D and C Pissarides (1994), Job Creation and Job Destruction in the Theory of Unemployment, *Review of Economic Studies* 61, 397–415.

Mortensen, D and C Pissarides (1998), Technologial Progress, Job Creation and Job Destruction, *Review of Economic Dynamics* 1, 733–753

Mortensen, D and C Pissarides (1999a), Unemployment Responses to 'Skill-biased' Technology Shocks: The Role of Labour Market Policy. *Economic Journal* 109, 242–265.

Mortensen, D and C Pissarides (1999b), New Developments in Models of Search in the Labor Market, in O Ashenfelter and D Card (eds.), *Handbook of Labor Economics,* vol 3, part 2, Elsevier.

Mortensen, D and C Pissarides (1999c), Job Reallocation, Employment Fluctuations and Unemployment, in J Taylor and M Woodford (eds.), *Handbook of Macroeconomics* vol 1, part 2, Elsevier.

Mortensen, D and E Nagypal (2007), More on Unemployment and Vacancy Fluctuations, *Review of Economic Dynamics* 10, 327–347.

Petrongolo, B and C Pissarides (2001), Looking into the Black Box: A Survey of the Matching Function, *Journal of Economic Literature* 39, 390–431.

Pissarides, C (1979), Job Matching with State Employment Agencies and Random Search, *Economic Journal* 89, 818–833.

Pissarides, C (1984a), Search Intensity, Job Advertising, and Efficiency, *Journal of Labor Economics* 2, 128–143.

Pissarides, C (1984b), Efficient Job Rejection, *Economic Journal* 94 (Supplement), 97–108.

Pissarides, C (1985), Short-Run Equilibrium Dynamics of Unemployment, Vacancies, and Real Wages, *American Economic Reivew* 75, 676–690.

Pissarides, C (1990/2000), *Equilibrium Unemployment Theory*, Basil Blackwell; second edition, MIT Press.

Pissarides, C (1992), Loss of Skill during Unemployment and the Persistence of Employment Shocks, *Quarterly Journal of Economics* 107, 1371–392

Pissarides, C (1994), Search Unemployment with On-the-job Search, *Review of Economic Studies* 61, 457–475.

Pissarides, C (2009), The Unemployment Volatility Puzzle: Is Wage Stickiness the Answer?, *Econometrica* 77, 1339–1369.

Postel-Vinay and J M Robin (2002), Equilibrium Wage Dispersion with Worker and Employer Heterogeneity, *Econometrica* 70, 2295–2350.

Rogerson, R and R Shimer (2010), Search in Macroeconomic Models of the Labor Market, forthcoming in O Ashenfelter and D Card (eds.), *Handbook of Labor Economics, vol 4*, Elsevier.

Rogerson, R, R Shimer and R Wright (2005), Search-Theoretic Models of the Labor Market: A Survey, *Journal of Economic Literature* 43, 959–988.

Schechtman, J (1976), An Income Fluctuation Problem, *Journal of Economic Theory* 12, 218–241.

Shimer, R (2005), The Cyclical Behavior of Equilibrium Unemployment and Vacancies, *American Economic Review* 95, 25-49.

Shimer, R and L Smith (2000), Assortative Matching and Search, *Econometrica* 68, 343–369.

Stevens, M (2007), New Microfoundations for the Aggregate Matching Function, *International Economic Review* 48, 847–868.

Stiglitz, J (1972), On the Optimality of the Stock Market Allocation of Investment, *Quarterly Journal of Economics* 86, 25–60.

van den Berg, G and G Ridder (1998), An Empirical Equilibrium Search Model of the Labor Market, *Econometrica* 66, 1183–1221.

Weill, P-O (2007), Leaning Against the Wind, *Review of Economic Studies* 74, 1329–1354

Wheaton, W (1990), Vacancy, Search, and Prices in a Housing Market Matching Model, *Journal of Political Economy* 98, 1270–1292.

Zenou, Y (2009), *Urban Labor Economics*, Cambridge University Press.