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ABSTRACT

We review the literature on agent-based labor market models by tracing its roots to the microsimulation literature, and surveying a selection of contributions made since the work by Bergmann (1974) and Eliasson (1976). Agent-based models have been applied to explain stylized facts of labor markets as well as for labor market policy evaluations. They also constitute a major part in agent-based macroeconomic models. Besides reviewing the various results achieved, we discuss modeling choices with respect to agents' behavior and the structure of interaction. Our overall assessment is that agent-based labor market models have given us valuable insights into the functioning of labor markets and the consequences of labor market policies, and that they will increasingly become an essential tool of analysis, in particular when the construction of large macro-models is involved.

1. INTRODUCTION

The labor market is in some respects a very special market, insofar as it interacts with many other economically meaningful domains. It is not just firms and workers meeting together to trade time for money. It is crucial to understand production, on one side, and income, hence consumption and savings, on the other side. As such, it is a key ingredient to any macro model of the economy.

In this chapter we provide an original perspective on the agent-based (AB) approach to the modeling of labor markets.[i] We start from a broad definition of the AB computational approach to economic modeling, according to which AB models are characterized by three features: (i) there are a multitude of objects that interact with each other and with the environment, (ii) these objects are autonomous, that is, there is no central, or "top-down" control over their behavior and more generally on the dynamics of the system, and (iii) the outcome of their interaction is numerically computed (Gallegati and Richiardi, 2009; Richiardi, 2012). To be able to compute the evolution of the system without the resort to external coordination devices, a basic requirement is that the system is specified in a recursive way (Leombruni and Richiardi, 2005; Epstein, 2006). This feature is not only of technical relevance for modeling purposes –as Bergmann (1990) puts it, "The elimination of simultaneous equations allows us to get results from a simulation model without having to go through a process of solution"– but bears a substantive belief on how the real systems behave: "The world is essentially recursive: response follows stimulus, however short the lag" (Watts, 1991).

Now, if we stick to this definition, the roots of AB models of the labor market must be traced back to two early studies that are generally not even recognized as belonging to the AB tradition: Barbara Bergmann's microsimulation of the US economy (Bergmann, 1974) and Gunnar

Eliasson's microsimulation of the Swedish economy (Eliasson, 1976). Both Bergmann and Eliasson developed a macro model with production, investment, and consumption (Eliasson had also a demographic module). As in the dynamic microsimulation literature that was emerging at the time the labor market was only one of the markets they reproduced in their models. However, they introduced two basic innovations with respect to the standard approach put forward by the father of microsimulation, Guy Orcutt (Orcutt, 1957, 1961), which make the labor market module a fundamental block in the microsimulation: they explicitly considered the interaction between the supply and demand for labor, and modeled the behavior of firms and workers in a structural sense. On the other hand, Orcutt's approach to microsimulation –or, as he called it, the "microanalytic approach for modeling national economies" (Orcutt, 1990)– was based on the use of what he considered as a-theoretical conditional probability functions, whose change over time, in a recursive framework, describe the evolution of the different processes that were included in the model. This is akin to reduced-form modeling, where each process is analyzed conditional on the past determination of all other processes, including the lagged outcome of the process itself.

Bergmann and Eliasson had a complete and structural, although relatively simple, model of the economy, which they calibrated to replicate many features of the US and Swedish economy. However, their approach –summarized in Bergmann et al. (1977)– has passed relatively unnoticed in the dynamic microsimulation literature[ii], which evolved along the lines identified by Orcutt mainly as reduced form, probabilistic partial equilibrium models, with limited interaction between the micro unit of analysis, and with abundant use of external coordination devices in terms of alignment to exogenously identified control totals.

On the contrary, the AB approach emerged with a focus on the analysis of evolving economic systems populated by heterogeneous interacting agents. This was at the expenses of the empirical grounding of AB models, which developed mainly as theoretical tools used to identify and study specific mechanisms that are supposed to work in real systems. Hence, the work of Bergmann and Eliasson could be interpreted as a bridge between the (older) dynamic microsimulation literature and the (newer) AB modeling literature, a bridge that has so far remained unnoticed (Richiardi, 2013).

The evolution of the AB approach to the modeling of the labor market can be further understood by referring to Ricardo Caballero's distinction between a *core* and a *periphery* in mainstream macroeconomics (Caballero, 2010). The core, as he suggests, is the dynamic stochastic general equilibrium approach (DSGE), while the periphery lies at the intersection of macroeconomics and other strands of literature such as corporate finance, with the investigation of issues ranging from bubbles to crises, panics, contagion, etc. According to Caballero, "The periphery has focused on the details of the subproblems and mechanisms but has downplayed distant and complex general equilibrium interactions. The core has focused on (extremely stylized) versions of the general equilibrium interactions and has downplayed the subproblems" (p. 87).

In their struggle with the mainstream approach, AB models have evolved along similar lines. The works by Bergmann and Eliasson were first attempts at replacing the core of macroeconomics with an AB alternative. Their goal to provide an AB macroeconomic model to be calibrated empirically was indeed very ambitious. After having languished for a few decades, the core approach to AB modeling has recently revived, with a key role played by the European Commission which has funded ambitious projects such as EURACE (Deissenberg et al., 2008), aimed at developing an AB software platform for European economic policy design, and CRISIS (Farmer et al., 2012), aimed at understanding systemic instabilities.[iii] These projects developed closed –no real or monetary flows are lost– macroeconomic models, in the same vein as in Bergmann's and

Eliasson's early work. The focus is on the interaction between different (possibly differentiated) markets –typically labor, goods and credit with some attempts to include also financial markets– with the goal of replicating the behavior of a real economy and qualitatively track the evolution of major economic time series. These approaches offer artificial labs for what-if-studies on "distant and complex general dis-equilibrium interactions", rather than forecasting tools as in the dynamic microsimulation tradition.

Parallel to the analytical tradition, a more peripheral approach has also emerged in the literature, with the aim to develop single-purpose rather than multi-purpose models. These models, which we label *partial models*, focus on heterogeneous and interacting agents in a particular market and are kept as simple as possible to isolate and investigate specific mechanisms of interest, possibly at the expenses of abstracting altogether from or offering an over-simplified representation of other dimensions and their feedback mechanisms. We shall review a selection of this AB periphery, in Caballero's parlance, later on. Interestingly, the partial modeling approach is often identified with the AB modeling paradigm itself, and it gained popularity as a way to illustrate the Santa Fe complexity paradigm (Gallegati and Richiardi, 2009).

An additional distinction can be drawn according to the research objectives of the models. Two main goals can be identified. One is to replicate a set of well-known stylized facts, possibly wider than what has been achieved by traditional analytical models (e.g. the wage curve, the wage distribution, the Beveridge curve, etc.). The second is to analyze the effects of specific policies (for instance training policies, employment protection legislation, unemployment benefits etc.). In recent decades, accelerated by the advent of econometric software packages with ready to use techniques for causal analyses of policy effects, most of the labor market policy evaluation focused on micro-analysis. It is well acknowledged that even though the analysis of micro-data gives valuable insights into the effect of policies, these evaluations only yield a partial picture (OECD 2005). Aggregated effects might be smaller than what analyses at the level of micro data suggest because of deadweight losses, substitution or displacement effects. Aggregate analysis that have the potential to capture the overall effect very often lack sufficient institutional details to be valuable for policymakers, or are incapable of addressing the magnitude of countervailing effects because many channels of interaction are shut down. AB models have been offering valuable insights into the mechanisms at work that reduce aggregate effects with respect to a simple aggregation of individual changes in behavior, and the kind of institutional details that can be incorporated.

The two goals of factual replication and counterfactual analysis are by no means exclusive. Indeed, a model that reproduces a realistic behavior of the labor market is *a priori* a good candidate to investigate the effects of a given policy. However, the understanding of the causal mechanisms triggered by a policy can sometimes benefit from a simpler model, cast at a higher level of abstraction. For this reason, while models in the core typically pursue both objectives, some models in the periphery are restricted to the latter.

In what follows we first elaborate on the value added of modeling the labor market through AB simulations (section 2). We then sketch the contributions by Bergmann (1974) and Eliasson (1976) (section 3), and review the literature that has developed since then by classifying the models according to their scope: from partial models used for analyzing particular policies and addressing stylized facts of labor markets (section 4) to models where an AB labor market is embedded in a macroeconomic framework aimed at reproducing the behavior of multiple interacting markets (section 5). We then discuss the main methodological features of all these models, which relate to the way individual behavior (section 6) and the interaction structure (section 7) are modeled. Section 8 offers our conclusions.

2. WHY AB LABOR MODELS?

A legitimate question is why we need AB labor models at all, or: What is the value added of AB modeling with respect to the mainstream (analytical) approach?

In short, the value added of AB modeling lies in the ability of weakening many of the standard assumptions at the same time. *Flexibility in model design*, which allows for richer and more complex specifications to address unexplored economic mechanisms and empirical phenomena, is the selling point of the methodology. And, indeed, this is how the discipline seems to have evolved ever since. As researchers have become more and more demanding, standard approaches to do things were abandoned, and the models, our main tools to think about the working of economies, were re-engineered to gain new insights.

Let us elaborate on this argument a bit more. A textbook on labor economics typically introduces students to the decision of households on how to optimally allocate time. Aggregation yields a market's labor supply as a function of the going wage rate. In a next step a firm's optimal demand for labor is derived which, aggregated up, yields a market's demand for labor. Particular assumptions on the households' preferences and the firms' production technologies make sure that labor supply is upward sloping and labor demand is downward sloping in wages so that there is a market clearing wage.[iv] We can go a long way explaining wage and employment patterns with a simple demand and supply model, and we can even apply it to analyze the effects of various policy interventions very often in a meaningful way. But the model has its shortcomings, most importantly that it does not allow, contrary to our everyday observation, for unemployment.

Consequently, the search for an explanation of unemployment has been the driving force in theory development during the last decades. Various proposals have been made but the unifying approach was always to give up with one or more of the simplifying assumptions. In efficiency wage models unemployment arises as firms do not lower wages to clear the market. This might happen because firms want to avoid shirking (Shapiro and Stiglitz, 1984) –unemployment works here as a disciplinary device, as the cost of job loss, hence the threat of firing, increases); or because firms want to minimize turnover (Stiglitz, 1974; Schlicht, 1978; Salop, 1979) –with above-market wages, the worker's motivation to quit is reduced; or because firms want to attract better workers (Stiglitz, 1976; Weiss, 1980; Malcomson, 1981); or because they do not want to lower the morale of the workforce, hence effort (Akerlof, 1982; Akerlof and Yellen, 1990). In another strand (or textbook chapter) we learn that wages are not set like in a spot market but rather by powerful unions or bargained over by unions and employer associations (see, for instance, Oswald 1985). Again, this allows for an explanation of unemployment. In a third route the assumption has been alleviated that vacancies are filled instantaneously. The search and matching models (Diamond, 1981; Mortensen, 1982; Pissarides, 1990) allow us to cope with the simultaneous occurrence of vacancies and job searchers as illustrated in Beveridge curves and the movements along the Beveridge curve over the business cycle. All these strands of the literature have paved their way into what we nowadays would accept as the mainstream explanations by working out the effects on labor market outcomes as one or more of the standard assumptions were given up.

Analytical models have gone a long way along this route. A good example of the sophistication is the work by Elsby and Michaels (2013) who introduce a notion of firm size into a search and matching model with endogenous job destruction. In our view, models of this kind are indeed quite an achievement. Still, in this example, there is no firm creation, or on-the-job-search, and empirically the model is able to generate only one quarter of the positive wage-firm size effect observed in the data. The authors dismiss this shortcoming by acknowledging that many other channels might be present, in addition to the interaction of surplus sharing with heterogeneity in employer productivity on which the model is focusing on. They cite efficiency wages, market power, specific human capital, and we could add union power, worker heterogeneity and the endogenous sorting of workers and firms into temporary jobs, as in Berton and Garibaldi (2012), or the questionable assumption of a constant return to scale matching function (Neugart, 2004; Richiardi, 2006).

Extensions into any of these dimensions are likely to prove analytically hard, and computational techniques have to be employed, at some stage. As the model complexity increases, not only analytical solutions of the aggregate steady state behavior have to be abandoned, but the aggregation problem itself becomes intractable.

Moreover, all these models still rest on the hypothesis of rational expectations (the assumption that individuals make no systematic errors), which can be considered the watershed between mainstream and more heterorodox approaches. The hypothesis is not without rationale: for one thing, the ability of individuals to act optimally based on rational expectations provides a well-defined benchmark for economic analysis. However, the plausibility of rational expectation has been criticized from within the mainstream camp itself. This is Caballero (2010, pp. 91-92) again:

> Rational expectations is a central ingredient of the current core; however, this assumption becomes increasingly untenable as we continue to add the realism of the periphery into the core. While it often makes sense to assume rational expectations for a limited application to isolate a particular mechanism

> that is distinct from the role of expectations formation, this assumption no longer makes sense once we assemble the whole model. Agents could be fully rational with respect to their local environments and everyday activities, but they are most probably nearly clueless with respect to the statistics about which current macroeconomic models expect them to have full information and rational information.
>
> […]In trying to add a degree of complexity to the current core models, by bringing in aspects of the periphery, we are simultaneously making the rationality assumptions behind that core approach less plausible.

Contrarily, decision making in AB models generally consists of learning processes based on adaptive behavior –with respect to expectations formation and strategy exploration– and sequential, rather than simultaneous, problem solving. Agents do not maximize inter-temporal utility under perfect information and unlimited computing abilities.[v] Optimal behavior can be obtained through various conscious or non-conscious learning processes for which a large array of formalizations drawing on the psychology literature and experimental evidence exists (Brenner, 2006), or through evolutionary selection (Arifovic, 1994).

Also, by not building on the rational expectations paradigm, AB models can be scaled up much more easily. Adaptive expectations generate a relationship between the dimensions of the decision making problem and its complexity that is roughly linear, rather than exponential as in the rational expectations paradigm. To see this, suppose there are n binary choices to be made (or one binary choice to be repeated over n periods). If the problem is solved simultaneously (inter-temporally), the choice set is composed of 2^n elements. If on the other hand the problem is solved sequentially, conditional on past choices, the choice set only includes $2n$ elements. Of course the result in the latter case could be highly suboptimal, but with a decentralized selection mechanism such as market competition or some sort of social or individual learning, the extent of sub-optimality can be highly reduced, without increasing too much the complexity of the overall optimization problem.

The bottom line is that AB modeling gives us a tool at hand to analyze patterns of behavior in the labor market that would not have been analyzable in the past. Will this AB tool give us a better understanding of the labor market or which policies to apply? We side with Richard Freeman who claims: “Of course not. Computer tools do not solve anything. You need ideas and data.” (Freeman, 1998, p. 19) But who proceeds by writing: “Still the new tools can sharpen our thinking about competing models of capitalism and allow us to assess alternative theories or explanations about which we could previously only hand wave.” We will try to assess how far AB labor researchers have gone in this respect and where they may want to (have to) go in the future.

2. EARLY MICRO-TO-MACRO MODELS

2.1 Bergmann’s model of the US economy

Barbara Bergmann was deeply influenced by Orcutt’s lessons while a graduate student at Harvard (Olson, 2007). However, her microsimulation model (Bergmann, 1974) departs from Orcutt’s approach in significant ways. The behavior of all actors is modeled in a structural sense: workers, firms, banks, financial intermediaries, government and the central bank act based on pre-defined decision rules, rather than being described in terms of transition probabilities between different states. Each period (a week), (i) firms make production plans based on past sales and inventory position; (ii) firms attempt to adjust the size of their workforce; wages are set and the government adjusts public employment, (iii) production occurs, (iv) firms adjust prices, (v) firms compute profits, pay taxes and buy inputs for the next period, (vi) workers receive wages, government transfers, property income; they pay taxes and make payments on outstanding loans, (vii) workers decide how much to consume and save, choose among different consumption goods and adjust their portfolios of assets, (viii) firms invest, (ix) the government purchases public procurement from firms, (x) firms make decisions on seeking outside financing, (xi) the government issues public debt, (xii) banks and the financial intermediaries buy or sell private and public bonds; the monetary authority buys or sells government bonds; interest rates are set. In the early 1974 version, only one bank, one financial intermediary and six firms, "representative" of six different types of industrial sectors / consumer goods (motor vehicles, other durables, nondurables, services and construction) are simulated. In the labor market, firms willing to hire make offers to particular workers, some of which are accepted; some vacancies remain unfilled, with the vacancy rate affecting the wage setting mechanism. Unfortunately, the details of the search process are described only in a technical paper that is not easily available anymore (Bergmann, 1973). Admittedly, the model was defined by Bergmann herself as a "work in progress", and was completed only years later (Bennet and Bergmann, 1986). The assumption of "representative" firms is particularly questionable from an AB perspective, although it is not engraved in the model architecture. However, the model is noteworthy for its complexity and for the ample relevance given to rule-based decision making.

2.2 Eliasson's model of the Swedish economy

Eliasson's (1976) "Micro-to-Macro model", which eventually came to be known as MOSES ("model of the Swedish economy"), is a dynamic microsimulation with firms and workers as the unit of analysis. A concise description of the model can be found in Eliasson (1977). The labor market module, which is of central importance to the model, is firm-based insofar the search activity is led by the firms that look for the labor force they require to meet their production targets.

Labor is homogeneous, and a firm can search the entire market and raid all other firms subject only to the constraint that search takes time (a limited number of search rounds are allowed in each period). Firms scan the market for additional labor randomly, the probability of hitting a source being proportional to the size of the firm (number of employed) and the size of the pool of unemployed. If a firm meets another firm with a wage level that is sufficiently below its own, it gets the people it wants, up to a maximum proportion of the other firm's labor force. The other firm then adjusts its wage level upwards with a fraction of the difference observed, and it is forced to reconsider its production plan. If a firm raids another firm with a higher wage level it does not get any people, but upgrades its wage offer for the next trial. Firms then produce, sell their products, make investment decisions and revise their expectations. Individuals allocate their income to savings and consumption of durables, non-durables and services. Each year the population evolves with flows into and out of the labor force.

The model was designed to address two issues: (i) offer a micro explanation for inflation, and (ii) study the relationship between inflation, profits, investment and growth. It was populated partly with real balance sheet firms, and partly with synthetic firms whose balance sheets were calibrated in order to obtain sector totals. Since its original formulation, the model has been updated and documented in a series of papers (Eliasson, 1991).

3. AB LABOR MARKET STAND-ALONE MODELS

3.1. Policy evaluations

A first AB "toy" model of the labor market, with only limited actors and actions being considered, is presented in Bergmann (1990). However, at those times the AB modeling approach was not shaped yet, and Barbara Bergmann clearly stated that her goal was to "provide an introduction to microsimulation". Bergmann's model is so simple that no more than 50 rows of BASIC code are needed to program it. Workers are homogenous, labor demand is exogenous, matching is random, the unemployed always accept an offer (with the exception of those who have just been laid off, and who have to wait one period to re-enter the labor market). Wages are not modeled, which is equivalent to assuming exogenous and homogeneous salaries. The fact that such a paper, with a whole paragraph devoted to explaining what random numbers are and how they can be obtained in BASIC, appeared in such a prestigious journal as the Journal of Economic Perspectives is a reminder of how recent the diffusion of personal computers is. At the same time, having what now looks as a basic tutorial in AB modeling published so early and so well, marks an (albeit not decisive) point for mainstream economics which is often criticized for obstructing the development of new ideas and approaches in the profession (Krugman, 2009)

Within this simple framework, Bergmann envisaged a stylized policy experiment: she added an unemployment insurance program (with limited-time benefits), and analyzed its effects on individual spells of unemployment and aggregate unemployment during recessions and recovery in the labor market. Her main result is that an unemployment insurance system might not increase unemployment during recession. The reason is that, although a particular worker may, on the basis of being eligible for unemployment benefits, refuse to accept a job offer, it paves the way for another worker who is offered that vacancy.

While one might call this a crowding-in effect, the major finding in Neugart (2008) stems from a crowding-out of workers not being part of the policy treatment which in this particular AB model is a training policy. The model consists of heterogeneous workers and firms that are allocated across different sectors. Workers differ with respect to their skills and firms located across sectors have distinct skill requirements. Workers may acquire skills which equip them with the necessary knowledge to work also in other sectors than their current one. Thus, should they become unemployed they may also apply for jobs outside of their current sector. In order to spur outflows from unemployment the government introduces a training policy which subsidizes workers' acquisition of skills. While on aggregate the policy has a positive effect on the outflow rate from unemployment, it also has distributional consequences. Those who receive government transfers and thus increase the marketability of their skills find jobs more easily. However, this occurs at the cost of workers who would have found a job in their current sector if they had not faced competition from the trained workers who are now able to look for jobs in sectors outside of their previous one. In a specular way to Bergmann's model, non-treated workers are crowded-out by treated workers reducing the aggregate effect of the policy with respect to a simple aggregation of the shorter unemployment spells of the treated workers.

Matching between heterogeneous workers and firms is also analyzed in Boudreau (2010). Here, firms pay different wages, and workers have initial skills and an endowment which they may invest to improve their productivity. The most productive workers are matched with the firms paying the highest wages. Those firms grow faster as they employ the more skillful workers. On the side of the workers, the higher wages are inherited to the descendant of each worker as the new wealth endowment. It is then analyzed how a redistributive tax changes inequality. Besides results being dependent on the specification of the technological growth, some interesting and counteracting mechanism on the incentive to invest in skills can be detected. With the transfer of funds to workers with high initial skills but low endowment competition for good paying jobs becomes fiercer increasing the incentives of other workers to invest. At the same time their funds are lower because of the redistribution scheme, making the overall effect on investments in skills ambiguous.

Ballot and Taymaz (2001) looked into three different training policies which all can be considered as a suitable proxy to actually conducted efforts spurring the acquisition of human capital: a subsidy to education and training activities, a policy which forces firms to spend a certain share of their wage bill on training activities, and a policy where firms receive subsidies for training if they hire unemployed workers. Results are that the first policy and to a smaller extent the third policy may improve long-run economic performance whereas the second policy does not. The effect of the first policy runs via an increase in the likelihood of a successful innovation. This effect is less powerful if the training policy is only on hired unemployed workers. The second policy is ineffective on the aggregate as it drives less profitable firms out of the market.

In most policy evaluations that use an AB approach the policy is exogenously varied. Typically, however, the policies may change as market outcomes change the payoffs for voters. In Martin and Neugart (2009) an attempt was made to endogenize policies choices. An AB labor market model is set-up where voters cast their vote on the type of employment protection system they prefer. It is shown that employment protection is neutral with respect to employment on average. However, employment rates decrease if at the onset of a more volatile economic environment the deregulation party was in power as backward looking voters blame the current party for the mal-performing economy and vote for the alternative which further depresses labor demand.

3.2. Addressing stylized facts of labor markets

There is a strand of AB models that have been developed in order to replicate some stylized facts of real labor markets and to understand the emergence of aggregate regularities from the micro behavior of individual units. In these models labor markets are still central, and although efforts were made to incorporate possible feedback processes from other markets, we still tend to classify them as being partial models as only selected other markets are typically incorporated.

The stylized facts that are most often targeted at are the wage- and Beveridge-curve, and Okun's law-curves, the form of the aggregate matching function, and the shape of the wage and firm size distributions. The wage curve (WC) postulates a negative relationship between the wage level and the unemployment rate (Blanchflower and Oswald, 1994; Card, 1995). The Beveridge curve (BC) describes a negative relationship between the unemployment rate and the vacancy rate, and Okun's law (OL) posits a negative relationship between the changes in the unemployment rate and the GDP growth rate (Prachowny, 1993; Attfield and Silverstone, 1997). The matching function (MF) relates the number of matches to unemployed job searchers and the number of vacancies (Blanchard and Diamond, 1990; Petrongolo and Pissarides, 2001), and is often assumed to show constant returns to scale. Finally, the income and firm size distribution, as many other economic variables, have been shown to be highly skewed, as predicted by a lognormal or power law functional form (Growiec et al., 2008 Gabaix, 2009).

Fagiolo et al. (2004) were able to reproduce the WC, BC and OL with an AB model focusing on the interactions of the firms with the output market. Building on their work, Tavares Silva et al. (2012) present an AB model with technologically neutral progress which features rising wage inequality. In a series of papers, Gallegati and coauthors (Russo et al., 2007; Bianchi et al., 2007, Delli Gatti et al., 2005; Delli Gatti et al., 2004) worked in the direction of filling the gap between firm demography and unemployment theory by focusing on the interactions of the firms with the financial system.

Richiardi (2004, 2006), modeled the matching process between workers and firms with on-the-job search, entrepreneurial decisions and endogenous wage determination. He showed that a negatively sloped WC and a constant returns to scale MF emerge only out-of-equilibrium during the adjustment processes toward the stationary state. In the stationary state, the WC is upward sloped, while the coefficients of unemployment and vacancies in the MF do not even have the right sign. These results question equilibrium models that take these aggregate empirical regularities as assumptions to start from.

Ballot (2002) models a dual labor market in the spirit of Doeringer and Piore (1971) hypothesis. He distinguishes between open-ended and temporary positions. Some firms have an internal labor market (ILM) for permanent positions where employees compete for promotions (seven grades are considered), while other firms do not. Promotions have two roles in the model. First, they are one way to fill a vacant permanent job, as they enlarge the pool of candidates for a job. Second, they operate as a screening device. Nominal wages are fixed, but given that workers differ in their productivity, the quality-adjusted wages are endogenous. Jobs require a minimal level of human capital, and firms have to invest in training if the hired workers are below that level. Moreover, firms can set a hiring standard for their vacancies, which can be either below or above the minimum level of human capital required. The higher the standard, the higher the expected quality of the selected worker will be, but the longer the expected duration of the vacancy. In setting their standards, firms look at the labor market tightness, and take the expected duration of the position offered into account. Hiring under a temporary contract involves paying the intermediation cost of a temporary help agency. Apart from that, temporary jobs have a linear cost in duration, while permanent jobs have non-linear costs in duration because of a seniority premium and redundancy payments. On the job search on the part of the workers is considered, at the cost of deferred leisure. Individuals and firms learn in the market, and adapt their behavior according to their past experience. Although the model only comprises 40 firms and 1700 individuals belonging to 800 households, it is roughly calibrated to the French labor market over the period 1972–1977, that is around the first oil shock. It is able to reproduce the changes in mobility patterns of some demographic groups when the oil crisis in the 1970s occurred, and in particular the sudden decline of good jobs. Moreover, ILMs for permanent positions are shown to have adverse employment effects, which are mitigated by the existence of a secondary labor market (made of temporary jobs or of open-ended jobs in firms without an ILM). In line with the microsimulation literature it is given a name (ARTEMIS). With a household composition and expenditure module which is, however, simpler than the labor market matching module, it goes already beyond a partial model.[vi]

Similarly, Dosi et al. (2006) may be considered as lying somewhere in between the partial AB models focusing on labor markets and those trying to incorporate feedback processes from other markets. They developed a model with an intermediate sector that produces machine tools, engages in R&D activity, and a final consumption good sector. The model is able to replicate a number of aggregate empirical regularities: investment is more volatile than GDP; consumption is less volatile than GDP; investment, consumption and change in stocks are procyclical and coincident variables; employment is procyclical; unemployment rate is anticyclical; firm size distributions are skewed (but depart from log-normality); firm growth distributions are tent-shaped.

4. LABOR MARKET MODULES EMBEDDED IN AB MACROECONOMIC MODELS.

Embedding an AB labor market in a macroeconomic model allows to analyze feedback processes arising from goods-, financial-, or credit markets on the labor demand of firms and the supply decisions of workers. These models pave the way for investigating policies which cannot be addressed in partial models in a meaningful way. In his prototypical model, Eliasson studied the effects of a regulation aimed at preventing layoffs without ample advance notice (Eliasson, 1977). He showed that such an EPL device actually fostered growth during the first years after implementation, as firms choose to make use of the workers they cannot lay off. In the longer run, however, wages are lowered and prices increase permanently, with possible adverse effects on welfare. But if the business sector is highly profit-centered, as he showed, the latter effect is only marginal, as competitive pressure forces firms to step up efficiency.

A major effort in attaining an AB model of the whole economy was put forward by the EU funded EURACE project (Deissenberg et al., 2008) which aimed at a proof of concept that an AB macroeconomic model including capital, goods, credit, financial, and labor markets within a spatial context can be developed and simulated. The resulting model has been used, with a focus on different sub-markets, in a number of papers addressing policy relevant questions.

Among these, Dawid et. al (2008, 2009) analyzed the regional allocation of funding of human capital investments in the presence of labor market frictions in a closed AB macroeconomic models. When commuting costs for workers between regions are high, a uniform distribution of funds to promote general skills for workers creates larger effects on output than a spatially unequal distribution. In the absence of commuting costs for workers, regional output levels evolve similarly no matter what spatial distribution of funds to promote general skills of workers is chosen. For positive and low commuting costs, however, a spatially concentrated policy performs better than a uniform approach, and furthermore the region which receives fewer funds outperforms the regions receiving the larger fraction of funds. These effects are due to the technological spillovers through the labor market and demand induced investment incentives for producers in that region. Using an augmented framework, Dawid et al. (2012) also looked into labor market integration policies establishing a trade-off between aggregate output and convergence of regions. There, it is shown that closed labor markets result in relatively high convergence but generate low output while more integrated labor markets yield higher output but lower convergence.

In another AB macroeconomic model also originating from the EURACE project Teglio et al. (2012) studied the impact of banks' capital adequacy regulation on GDP growth, the unemployment rate and the aggregate capital stock. Results are that allowing for a higher leverage gives a boost to the economy in the short run, but can be depressing in the longer run because firms become more fragile, possibly trigging credit crunches.

These examples as well as other attempts to build AB macroeconomic models reviewed in other chapters of this Handbook, are promising with respect to a meaningful inclusion of labor market modules into a larger framework. They have also shown that particular policies targeted at submarkets might gain from being studied in closed macroeconomic models as they can trigger important and non-trivial feedback processes driving aggregate outcomes.

5. BEHAVIORAL RULES

In describing the set-up of AB models and the insights that have arisen we hardly went into the specific modeling choices on how agents decide and interact. Both are crucial assumptions which necessitate a closer look. Let us firs elaborate on the choice of behavioral rules.

Giving up rational expectations as the prime input to modeling agents behavior, as it is done in the AB approach, opens up a whole range of possibilities on how to model agents' behavior. This is reflected in how firms' and workers' choices are modeled in existing AB labor market models. We find examples of firms choosing (among applicants) randomly (Tassier and Menczer, 2008) as well as more sophisticated behavior. Ballot and Taymaz (1997, 2001) modeled firms' search for more efficient technologies using genetic algorithms. The same approach is taken in Tesfatsion (2001c) where firms and workers adjust their worksite behavior involving recombination, mutation and elitism operations favoring more suitable strategies. Similarly, Tassier and Menczer (2001) apply a local selection algorithm with which they allowed more successful agents to reproduce themselves. A rule based approach has been followed by Boudreau (2010) who let workers choose their level of investment in human capital such that labor market prospects of higher ranked workers are matched. The rule based approach also features prominently in Dawid et al. (2008, 2009, 2012) who model agents' behavior using rules of firm choices coming from the management science literature. Rules with adaptive behavior of agents have been used by Richiardi (2006) to model the decision on whether to search for a new job. Here workers compare present and future expected income, with expected income being formed adaptively to arrive at a decision. Fagiolo et al. (2004) used adaptive rules for the adjustment for firms' vacancies based on past profit growth, wage setting and updating of workers' satisficing wages. In some contributions, as e.g. in Axtell and Epstein (1999), there is a mix of behavioral rules, with some workers choosing randomly, others imitating, and yet others just doing the right thing. Discrete choice models have been used by Neugart (2008) and Martin and Neugart (2009), and Gemkow and Neugart (2011) employ reinforcement learning to model the choice of agents on how much to invest into the size of a network of friends.

As we can see from these examples, AB (labor) market modelers have imposed quite distinct assumptions on agents' choice behavior. Although sometimes backed by empirical evidence there remains a flavor of arbitrariness. It is also not always apparent to which extent results are sensitive to these modeling choices.

There are several ways to proceed in future times. Contributions could be extended by further robustness tests that exchange parts of the model and rerun simulations in order to validate that at least qualitatively the results do not change. Another approach which has been pursued at least partly in the EURACE project is to implement rules as they are typically applied in firms for standard decisions such as stocking up. Actually, these rules are very often already implemented in standard software to which firms recur organizing their production processes. In that sense, it would constitute a modeling choice mimicking firms' behavior very closely. Finally, we would like to see more attention being paid to the findings of experimental economists or modeling choices made in AB contributions being backed up by laboratory experiments (Duffy, 2006; Contini et al., 2007).

6. INTERACTION STRUCTURE

In labor markets social interaction plays a prominent role. Access to information on job opportunities is embedded in an individual's social network. Additionally, in a world of asymmetric information, matching of vacancies to job searchers is alleviated by the social capital of a network with one worker referring another. Thus, it does not come as a surprise that the role which networks play for labor market outcomes is increasingly acknowledged (Ioannides and Loury, 2004; Ioannides, 2013). What is surprising, however, is that AB contributions to this literature are sparse. The AB approach seems to be a natural candidate to address these research questions, with a focus on labor market outcomes from heterogeneous agents interacting within and across social groups, and with group formation possibly being endogenized.

An early contribution to this strand of AB models is Tassier and Menczer (2001) who set up a labor market model assuming that there are a fixed number of jobs and randomly assigned wages in the economy. Agents search for these jobs by two means: on the one hand they may devote part of their resources on directly finding a job. On the other hand, they may expand effort in making friends that eventually may convey information on job openings. Simulations reveal the emergence of small world networks which, however, do not inhibit the transfer of information. Secondly, it is found that individuals exert too much effort on finding jobs. While individually optimal, this strategy is suboptimal from a social point of view.

The network of agents is also endogenous in the labor market model developed by Gemkow and Neugart (2011). However, while Tassier and Menczer (2001) zoomed into the role of networks for the transmission of information on job openings, the emerging network in Gemkow and Neugart helps workers who apply for a job to overcome the asymmetric information problem which typically exists between prospective employers and employees. It is shown that those workers who achieved to build up a network of employed friends experience shorter spells of unemployment at the cost of the agents who have less elaborated networks and therefore rank low on the applicant's lists of prospective employers because they lack referrals. Interestingly, the unequal allocation with respect to unemployment durations diminishes with a more volatile labor market because workers allocate fewer resources on building up a network as it becomes more likely that their friends are themselves unemployed and cannot at as referees for prospective employers.

As in their earlier contribution, Tassier and Menczer (2008) focus on the role of a networked labor market in transferring information on job openings. Contrary to the two contributions just described, however, in this work they fix the network structure. The aim is to investigate to which extent the randomness of two overlaying networks has an influence on the labor market success of individuals measured by their employment rates. In particular, there is a social network that comprises agents of the same ethnicity or the same gender, and a network of jobs, say of engineers, within which information on vacancies is spread. It turns out that employment rates of social groups with a more random network are larger if connections in the job network are random. Contrarily, if the job information flows are non-random, a less random social network fares better. What stands behind these results is that higher randomness means better access to information that is outside of one's social group. Higher randomness, however, also implies that information within a social group is more likely to leak outside to the advantage of the members of the other social groups.

In an AB model on worker protest Kim and Hanneman (2011) place agents with limited sight in a neighborhood. Workers relate their wage to those of their neighbors and are more likely to protest as the difference becomes larger. As they protest they run the risk of being arrested which is a function of similarly acting agents in the local area. It is shown that if wages are more unequally distributed protests become more frequent, intensive and persistent, and that the group identity on the local level contributes to the global synchronization of the uprisings.

These attempts to implement a network structure in AB labor market models are also promising avenues to depart from for future work. What we have in mind are AB models of labor markets with network structures that are used to evaluate the effectiveness and efficiency of policies in the light of agents having social preferences or being embedded in distinct neighborhoods so that positive as well as negative feedbacks on outcome variables might arise. Such a research agenda would depart from the usual microeconometric evaluation exercise which focuses on individual effects only by completely abstracting from the social environment of agents. We believe that applied in this way, AB labor market models may potentially give important insights for policy making.

7. CONCLUSIONS

We reviewed the development of AB models of the labor market to a large degree along the lines of the number of links modeled to other markets. We now ask to which degree the integration into broader frameworks is possible and desirable. Should we aim for models of the whole economy, with additional features steadily implemented (and possibly sequentially tested against the real data)? Or should we rather become acquainted with papers that provide an answer to a specific research question with exogenously given links to other parts of the economy?

From within the mainstream approach, Caballero (2010, p. 90) warns us against "an El Dorado of macroeconomics where the key insights of the periphery are incorporated into a massive dynamic stochastic general equilibrium model." To him, the core should remain "a benchmark, not a shell or a steppingstone for everything we study in macroeconomics", to be used " as just one more tool to understand a piece of the complex problem, and to explore some potentially perverse general equilibrium effect which could affect the insights isolated in the periphery".

We argued that one of the main advantages of the AB approach is that it allows the inclusion of features that account for potentially important economic mechanisms to a larger extent than the analytical approaches. The flexibility, however, has its own drawbacks. Most importantly, the small cost of growing large models can produce black boxes which are difficult to calibrate, analyze and interpret. Interpretation of an AB model can be done either with the help of an analytical model that gives some benchmark behavior in a simplified setting, or by means of extensive statistical testing and sensitivity analysis (Grazzini et al., 2013). When a model becomes too large, the probability to have an analytical benchmark quickly drops to zero. At the same time, the complexity of a sensitivity analysis rapidly increases. Also, the structural estimation of AB models is problematic and only models with few parameters have so far been properly estimated (Grazzini and Richiardi, 2013). Describing the behavior of a system through simulations provides a more tarnished picture than showing first derivatives. Moreover, the difficulty of the task inevitably increases as the model grows bigger.

The importance of having relaxed many assumptions of simpler models into a more general framework can be assessed only by reinstating them one by one, which suggests a gradualist approach to model development, and that small- or medium-scale AB versions of the periphery type are here to stay and prosper. However, AB models are more amenable to extensions and scaling up than their analytical counterparts. The technology is ready for the big effort of combining many research insights into larger models, much in the same way as climatologists increasingly do. This will not eradicate the uncertainty we face with respect to the behavior of our economies, but will reasonably offer a much better alternative to the models currently used by governments and central banks all over the world. In the words of Orcutt (1987), “much remains to be achieved before the dream of combining research results, gleaned at the micro-level, into a powerful system that is useful for prediction, control, experimentation and analyses, on the aggregate level, is realized”. However, the premises are there for big improvements to be obtained in the near future.

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[i] In previous attempts to take stock of AB modeling in Economics, as in the Handbook of Computational Economics edited by Judd and Tesfatsion (2006) or in the two special issues edited by Leigh Tesfatsion (Tesfatsion, 2001a, 2001b), labor market issues where touched upon only marginally. In particular, the Handbook contained no special chapter devoted to the labor market.

[ii] In his influential review of dynamic microsimulation models, O'Donoghue (2001) classifies Eliasson's work as a microsimulation of labor demand, with firms as the (only) micro unit of analysis, and makes no mention of Bergmann's model.

[iii] EURACE: FP6-STREP grant, 2006-2009. CRISIS: FP7-ICT grant, 2012-2015.

[iv] Only under very restrictive and implausible assumptions the aggregate supply and demand curves can be derived as the result of the optimal choice of a representative household and a representative firm (Kirman 1992). However, in order to obtain comparative static results, most models implicitly pretend that these assumptions hold.

[v] Giving agents rational expectations in an AB model seems to be not feasible. Critics may argue that this is the true reason why AB modelers recur to learning behavior –a view that we do not support.

[vi] ARTEMIS has now evolved in WorkSim, which at the moment of writing this chapter appears to be at an advanced development stage.