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Productivity consequences of workforce ageing -

Stagnation or a Horndal effect?[1]

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Abstract
Data linking the production of value-added at the plant level to the individual employees provide an opportunity to deepen the understanding of how the labor force composition relates to productivity performance. In view of the anticipated aging of the workforce in industrialised economies a body of research has emerged that indicate that individual productivity has a more pronounced hump-shape than the wage profile. This paper studies these issues by examining the composition of the workforce at the plant level in relation to the productivity performance of the plants. Our data cover the Swedish mining and manufacturing industries 1985-1996. The fact that older workers selectively work with older capital may have biased results found in the literature. Endogeneity of workforce composition poses serious estimation problems, but our attempts to cope with these problems tend to indicate that biases in general go in the direction that productivity of the young is overestimated and the productivity of the old is underestimated.

Introduction

A growing population where every successive cohort is larger than the preceding one will, in general, be characterized by a youthful, *progressive* age structure. This relation between cohort growth and age structure is not only valid for the total population but also for the working age population. Positive cohort growth rates lead to an age profile dominated by young adults whereas negative cohort growth rates give a dominance of older adults.

In this paper we address the question of how such changes in the age composition of the working age population will affect productivity growth. Two different hypotheses are relevant. The first one is based on productivity measurement on the individual level. Here, most studies indicate that labor productivity peaks somewhere between 30 and 50 years of age. This suggests that a prime-aged workforce would be more productive than both a young-aged or old-aged workforce.

The second hypothesis is based on the experience of the Horndal steel-plant in central Sweden. Between 1927 and 1952 this plant experienced a mean annual growth rate in productivity of 2.5 percent in spite of the fact that no major investments were undertaken (Genberg 1992). The first economist to discuss the Horndal effect was Erik Lundberg (Lundberg 1961). Later, it formed an important part of Arrow's learning-by-doing argument (Arrow 1962). An important aspect of the Horndal story is that the steelwork had a very aged workforce. In 1930, more than a third of the workers at the Horndal steelwork were above 50 years of age, compared to only one-in-five of all non-agricultural male workers in Sweden. In 1950 almost half of the workers at Horndal were above 50, compared to one-in-four among non-agricultural male workers in general. The Horndal experience, thus, suggests that workforce ageing is not a problem for productivity. To the contrary, an ageing workforce was compatible with rapid increases in labor productivity through a learning-by-doing effect.

The existence of two competing, but not exclusive, hypotheses on the effect of workforce ageing on productivity clearly calls for a more thorough empirical study based on micro data. Although the two hypotheses are competing it is important to recognize that both may be true and conclusions regarding the productivity of an ageing workforce in the aggregate are not as obvious as it may seem. Different age groups substitute or complement each other and the effect of other production factors should also be considered. Thus, the aggregate effect is not necessarily a simple summation of the productivity of the age groups. The most productive combination of different age groups at the plant level may have other properties than would be indicated by the sum of individual productivities. Here, however, the focus is on whether the age combination at the plant level is primarily determined by the individual characteristics of the workers, making physically more productive young workers the natural choice, or by Horndal, learning-by-doing, effects on productivity, making older workers an important building block of efficient production.

In this study we will use a panel of employer-employee matched data from Statistics Sweden covering the 1985-1996 period. Plant level data are from the Swedish Manufacturing and Mining Survey and contains information about sector, number of white-collar and blue-collar employees, value of output and value added. Employee data are from the RAMS (previously ÅRSYS) database at Statistics Sweden and contain information on the age and education of individuals employed in Swedish manufacturing and mining establishments. By matching these two datasets we have been able to obtain measures of the age and educational composition of the workforce of the establishments.

The strength of this data is the combination of employee data, output data and several observations for each plant. This allows us not only to compare the productivity levels of plants with different age and educational structures. Thanks to the panel structure, we can also control for possible plant-specific effects and, in addition, use lagged variables as instruments for potentially endogenous measures of current age structure.

If the hypothesis based on individual-level productivity measures is correct we should expect plants with a high share of prime-aged workers to be the most productive. On the other hand, if the Horndal hypothesis is valid then workforce ageing at the plant level should nevertheless be associated with increasing productivity.

Earlier studies using employer-employee matched data sets have to a large extent focused on a comparison between the age profile of earnings and the age profile of estimated productivity, with the purpose of testing the seniority wage hypothesis that wages for the elderly are higher than their marginal productivity. Notwithstanding the importance of this issue, we argue that the productivity profile as such is of considerable importance in view of the ageing of the labor force that will characterize many countries in the next 10-20 years. In this paper, therefore, we focus on the productivity issue and refrain from looking at earnings profiles.

The paper is organized as follows. In section 1 the estimated model is described. Section 2 presents the results from OLS regressions relating plant-level productivity to age structure and educational levels in the pooled data. In Section 3 we introduce plant-level fixed effects based on the argument that the productivity levels of a plant are strongly influenced by quasi-fixed factors such as basic design and machinery set-up. Section 4 presents the results from an instrumental variable regression that controls for the possibility of endogeneity bias in the estimates of ageing effects. Section 5 contains a complementary analysis of workforce age structure in start-up plants and plants that are closing down. Section 6 discusses the implications of our results.

1. Estimated model

The estimates presented below are, at this stage, not based on an explicit theoretical model. Instead, the aim of the specifications is to answer the empirical question of how labor productivity at the plant level, measured by value added per employee, is related to the age composition of the labor force without imposing any given theoretical structure. Throughout, we will use a log specification, that is, log value added per employee as dependent variable and log of the age variables. This limits issues with asymmetric sample variations, given the highly skewed shape of the distribution of per worker value added. Moreover, using logs makes it possible to include all the age shares in spite of the fact that the non-logged values add to one. This has the advantage of simplifying interpretation.

Two specifications of age effects have been used. First, an age share model where the workforce has been divided into three age groups: less than 30 years, between 30 and 50 years, and above 50. This division is in essence arbitrary, but it corresponds roughly to the earliest part of working life, prime age working life, and later part of working life. Moreover, this division corresponds to a division that we have been using consistently in a number of different studies of age effects on the economy. One difference, however, is that the 50+ group here also includes people above 65, the reason being that this group is too small to allow a separate analysis.

The only explicit control variable we report here is mean length of education. This variable is based on an assumption on the education length of people with primary, secondary and tertiary education. No other control variables are reported here, since our aim is not to provide any comprehensive explanation of the general development of productivity but rather to focus on the two competing hypotheses above. To avoid issues of omitted variable bias fixed effects have been used to account for the influence of unmeasured and unobserved variation across plants.

The Swedish Manufacturing and Mining Survey (SMMS), provide data on somewhere in between 9000 and 12000 establishments depending on the year, while the Regional Labour Market Statistics (ÅRSYS/RAMS) contain data for around 550000-750000 individuals employed within mining and manufacturing in the month of November different years. After merging the data sources we end up with around 8000-9000 establishments in each year, with a quite stable average of around 80 employees per plant for the years 1985-1996.

Table 1.1 displays some descriptive statistics for the total merged sample. Value added, education and mean age are all expressed as averages, education and mean age in years, and value added as thousands of SEK per worker in 1968 years constant producer prices. Note that the standard deviations of mean age and mean years of education are fairly low and gets even lower in the larger plants. While there is a drift upwards in both mean age and mean education over the period, most of this is due to selective firing of the young and the low educated in the recession Sweden experienced in the beginning of the 1990s.

2. Age effects on productivity without controlling for fixed, plant-level effects

In table 2.1 we present the results from estimating age effects on productivity when no plant-level fixed effects are used. Four different specifications are presented: Only age shares (1), age shares and education (2), age shares and education estimated for small and larger plants separately (3, 4). The break-off point between large and small plant has arbitrarily been set at an average of 50 employees during the existence of an establishment.

The estimates give a strong support for the hypothesis that plant-level productivity is positively influenced by a high share of prime-aged adults in the workforce, whereas a high share of young adults has a less beneficial effect. Note also that the effect of old workers is negative. The results here, thus, fit with what we should expect from studies of age effects on individual productivity. The result is also in line with the findings of other studies of this issue (Haltiwanger, Lane et al. 1999; Haltiwanger, Lane et al. 2000; Crepon, Deniau et al. 2002; Ilmakunnas and Maliranta 2002; Hellerstein and Neumark 2004; Ilmakunnas and Maliranta Forthcoming).

Introducing controls for education does not change this conclusion. The age effects become somewhat less pronounced but the basic pattern is still very strong. The pattern is also present both among small and larger plants, although it is much stronger in the sample of larger plants. This is what one should expect given that smaller plants will be more constrained in achieving an optimal mix of workers.

Note that since the shares sum to one some care has to be taken in interpreting the coefficients in the table since the age share variables cannot vary independently of each other. Thus, an increase in the share below 30 must be accompanied by a decrease in the other age group shares and the effect on productivity depends on how this decrease is distributed over the age groups. For example, according to column (1), an increase in the young workforce share has a positive elasticity of 0.02 but if the corresponding decrease takes place in the prime aged group the net effect is predicted to be negative nevertheless, while if it takes place in the 50+ group the positive effect would be reinforced. Therefore it is essential for the interpretation how ageing takes place. A swelling of the prime aged group at the expense of the young will have positive effects while an increase of the old age group at the expense of the young in this case will have negative effects.

Since the estimated coefficients are elasticities and a one percent change in the share of young workers automatically corresponds to a percentage change in the other age shares that differ dependent on their initial size, it is somewhat ambiguous exactly how the impact will look. Assume for instance that the distribution is 30 percent young, 45 percent middle age and 25 percent old, then the estimates in column (1) imply that a ten percent decrease in the young to 27 percent combined with a corresponding increase of the old to 28 percent will *decrease* productivity by around 0.3 percent. However, if it is the prime aged group that increases by 3 percentage points this is only two thirds of a ten percent increase for that share and hence productivity will *increase* in this case by $(0.128*(10*(0.30/0.45))-(0.02*10))$ percent, i.e. around 0.65 percent. In general the effect of a change thus depends on the initial values. In practice, however, we will in general have a distribution of age shares counteracting extreme effects.

Table 2.2 presents an alternative estimation of the age effects with a much simpler interpretation. Here the log of *mean age of the workforce* at the plant is the age variable instead of age shares for young, prime aged, and older workers. If the Horndal hypothesis is valid, we should expect *mean age* to have a clear positive effect on labor productivity. However, as the results show, these estimates give the opposite results. Increasing workforce age is associated with lower productivity. To get an impression of the magnitude, consider that mean age is on average around 40 and a one year increase therefore corresponds to an increase of 2.5 percent which according to the estimate in column (4) results in a decrease in productivity by a little less than 0.8 percent. The conclusion is that when labor productivity across plants and over time is compared without taking into account the possible effect of plant-level quasi-fixed factors, workforce ageing stands out as a potential threat to productivity. Judging from these estimates, managers would be well advised to consider how to get rid of older employees and instead hire prime age adults with higher levels of productivity.

3. Age effects on productivity with control for fixed, plant-level effects

Table 3.1 presents the results from estimating the same specification as in table 2.1 with the difference that plant-specific effects have been controlled for. This has been done by subtracting the mean value over time of plant-level value added per worker, age shares and education levels from the variables before they are put into the regression. The regressions, thus, are performed on deviations from the plant-level, time-series mean.

The rationale for this procedure is that plant level productivity to a substantial degree may be influenced by the basic design of the plant at the time it was established. Examples of factors that can be costly to change in an already established plant are location in relation to transport infrastructure, the size of the premises and buildings, systems for internal transport, the physical set-up of the production flow, the dimension of tubes, vessels etc. To the extent that buildings have been designed to accommodate a specific type of machinery it may also be difficult and costly to make major changes in the type of machinery used in the plant. Taken together, the quasi-fixed factors imply that the production characteristics of plants to a substantial degree may reflect the technological level and relative prices of production factors at the time they were designed and built. If, in addition, the age structure of the labor force is influenced by how long a plant has been in operation, then it might be the case that the estimated parameter for different age variables captures not the productivity effect on labor force ageing but instead serves as an indirect measure of the technological age of the industrial plant.

By removing the plant-level mean of the variables we control for this risk. What we get then is a within estimate of the ageing effects that should not be influenced by partial correlations between quasi-fixed factors and labor-force age structure.

As shown in table 3.1, removing plant level means from the variables does change the estimated age effects. In the base regression the strong positive effect of prime aged workers is reduced, whereas the effect of older workers goes from negative to positive. Furthermore, the positive effect of young workers becomes negative. The implied hump shape of productivity over age thus tilts such that an older workforce becomes comparatively more productive than implied by the estimates in the previous section. Comparing the estimates obtained for large and small plants it is clear again that the age effects are much more pronounced for larger plants then for small plants. In both cases, though, the age profile gives some support for the Horndal hypothesis: Large shares of young adults in the workforce have a negative effect on productivity. Prime aged adults have positive effects on productivity and so has old workers, albeit to a lesser extent. Thus, an ageing of the workforce can improve productivity depending on the composition of ageing.

A positive relation between ageing and productivity is also demonstrated in table 3.2 where productivity is related to the mean age of the workforce. Here the same specifications as in table 2.2 are used with the difference that plant-level means have been subtracted from the variables. The removal of plant-level fixed effects has a strong influence on the estimated age effects also in this case. In Table 2.2 age effects were negative. The within-estimation of age effects, however, indicates substantial positive effects of ageing on productivity. The largest estimates are found among large plants. This, then, is the same pattern that was observed in the Horndal steelworks: Increasing workforce age accompanied by increases in productivity.

So far, then, testing the Horndal hypothesis vis-à-vis the individual-effect hypothesis has led to apparently somewhat contradictory results. Tables 2.1 and 2.2 show quite conclusively that plants with a workforce dominated by older workers are less productive than plants with a dominance of prime-aged workers. However, when the relation between ageing and productivity is estimated within plants the Horndal pattern starts to emerge. A result in the same direction is obtained by (Haltiwanger, Lane et al. 1999) when they analyze the effect of workforce age not on the level but on changes in productivity.

The conclusion, as we see it, is that the lower productivity of plants with many old workers is not due to declining productivity of individual workers as they get older. Instead it should, as we show below, be explained by the fact that high concentrations of old workers are found in older plants where the production technology is not entirely up-to-date. Even if efficiency increases as the workforce age, the productivity of an old plant can be still be lower than it would be in a newly built, modern plant. Or, to rephrase the conclusion: Yes, if we observe a plant with a very old workforce we would probably be correct, on average, if we assume that this is a plant with relatively low labor productivity. However, it would be erroneous to infer from this that rejuvenating the workforce could increase productivity. Instead, our empirical evidence indicates that throwing out old age workers to replace them with young adults could in fact lower productivity. From Table 3.1 it is apparent that a replacement with prime age adults on the other hand would be advantageous. However, the average mobility is much less for prime aged than for young adults so the former mechanism will tend to dominate.

The Horndal story provides some evidence also on this point. During the 1930s managers had become aware of, and preoccupied with, the high mean age of the workforce at the Horndal steelwork. During a crisis in 1937 they, therefore, decided to get rid of the oldest workers, some of them above 70 years of age. Contrary to their expectation, however, the ensuing decline in the mean age of workers did not contribute to higher productivity. Instead the overall positive trend in productivity was broken and it did not recover until after about eight years when the mean age of the workers started to increase again.

4. IV-regressions of the ageing effect

In the above section we used fixed plant effects to control for a possible influence of plant age on both workforce age and productivity. This approach controls for any systematic differences across plants that affect productivity and remain constant over time. But it cannot capture the possible effect of an externally generated productivity shock. Such a shock can generate correlated changes in labor-force age structure and labor productivity that are not related to the effects of workforce ageing per se. The argument here is that changes in the age structure of the workforce can be endogenous and, therefore, that OLS estimates of the ageing effect can be biased. Even worse, the control for fixed effects can introduce such a correlation if there are persistent but not constant differences in reactions across plants. This well known problem in panel estimation is often handled by using instrumental variable regressions.

To make this point concrete, suppose a negative productivity shock hits a plant, and assume that this leads to quits of the old workers preferentially, not because they are less productive but because they have other options like early retirement. That would introduce a spurious positive correlation between productivity and the share of old workers. In the Swedish context this may have occurred to some extent although labor market regulations would rather tend to create the opposite bias by making it more difficult and costlier to fire the old than the young.

Controlling for fixed effects, which is tantamount to subtracting the averages of variables within plants, may introduce endogeneity bias, even if there is no such correlation between explanatory variables and the contemporary random shocks. This well known dynamic bias problem arises because random shocks in the current period may be correlated to the average age structure even if there is no such correlation to the current age structure. This is because the average includes future values and thereby any future influence from the shocks, so even if the composition of the workforce a given year is independent of the productivity shocks encountered this year, its adaptation the next year will be part of the average, which thus may exhibit a correlation that creates endogeneity bias.

Another possible critique is that the model we have estimated above suffers from omitted variables, for example, by ignoring the influence of demand factors. One way around this problem is to use fixed time effects or regime dummies that can account for the changes over time in variables that are not in the model.

In this section, therefore, we present results where the effect of labor force ageing is estimated using instruments for both age structure and education as well as estimation results for models using fixed time effects. A regime dummy (regime=1 if year≥1991, otherwise zero) was also tested as a more parsimonious way to account for the recession.

IV regression depends on the availability of good instruments for the endogenous variables. For the education variable and the mean age variable we were able to find such instruments. This is not the case for the age share model. We have found instruments that are valid in the sense that they are not correlated with the residuals in the second-stage regression. However, these instruments have been weak with respect to their ability to generate good predictions of the endogenous age share variables.[3] Below, therefore, we only present the results for the mean age model.

Moreover, we have not tried to establish if the relation between log productivity and log mean age could be curved instead of linear. While that is likely to be the case, a both relevant and valid instrumentation of the squared variable is precarious. Anyway, the actual variation in mean age of the plant workforce in our sample is not at all sufficient to admit extrapolation to the extremes of age variation. Although it is a common habit in the literature to estimate age productivity profiles in this way it cannot be considered a rigorous estimation practice. Since our purpose in this paper is not to compare productivity and earnings profiles there is no need to try to make precise the non-linearity that is likely to be present. Over the ranges encountered in empirical data the linear approximation seems quite sufficient to conclude that workforce ageing per se hardly can be considered any major future problem.

The results of the instrumental variable regressions are presented in table 4.1. These results show that controlling for possible endogeneity bias further strengthen the picture that workforce ageing at the plant level is associated with increasing productivity. The IV-based estimates of the ageing effect are about six to eight times higher than the fixed effect estimates. According to these estimates, a one-year increase in the mean age of the workforce from 40 to 41 years, that is a 2.5 percent increase, would imply a four to five percent increase in productivity. The IV estimates, thus, suggest that the Horndal effect is very much alive and that ordinary OLS estimates are seriously biased downwards as they appear in Table 3.2 and even more in Table 2.2.

A similar result is obtained by (Aubert and Crépon 2003). Looking only at the OLS estimates in the pooled data they find, as we did, a negative correlation between age and productivity. However, when they use instrument variables to control for the endogeneity of workforce age structure and fixed establishment effects, this negative correlation turns positive.

Moreover, the TSLS estimates in table 4.1 are only marginally affected when we include a regime dummy in order to control for unexplained time-effects. Inserting a full set of year dummies (not reported) does not change this conclusion. Thus, the identification problem that usually arises from the

[3] In the technical appendix we make this assertion precise. Although the age share results are not robust the basic hump shape and its tilt towards older age groups as we introduce fixed plant effects is still apparent.

correlation between age effects and time effects (and to some extent education) is also ameliorated in the IV-estimates.

5. Start-ups and closures

The sample used in the estimations above not only contains plants that have been in existence during the entire 1985-1996 period. Plants that have opened up or closed down are also present in the sample. This allows for a check of the assumption that productivity levels and labor-force age structure are correlated with technological age.

If it is the case that new plants are more up to date, and more likely to employ young workers then we should expect that plants with high value added per worker, and high shares of young workers, are more likely to be start-ups than plant with low value added per worker, and low shares of young workers. Similarly, plants with low mean age of workers should be likely to be start-ups.

These predictions are tested in Table 5.1. Here a plant is defined as a start-up during the first year it is present in our sample (if this year is not 1985). The test has been performed with a binomial logit model. As can be seen from the results plants with high value added per worker, high shares of young workers, and, to some extent, plants with high shares of prime aged workers are more likely to be start-ups. Plants with high shares of old workers and with high mean age, on the other hand, are less likely to be start-ups.

This data set, thus, strongly supports the idea that new plants embody a technology that generates higher value added per worker and, also, that new plants tend to have a younger workforce.

In table 5.2 the focus is shifted to the closure plants. Here, a plant is defined as a closure plant during the last year it is present in our data set (if this year is not 1996). If firm behavior is rational, a plant should not be closed down if it would be possible to restore profitability by an adjustment in the labor force or by not too complicated changes in the production process. However, if a plant has become technologically out-of-date a closure is often the most viable alternative. This assumption is corroborated by the estimates presented in table 5.2. What these estimates show is that plants with high levels of value-added per worker are unlikely closure candidates. Similarly, plants with a high share of young adult workers, indicating a more modern plant are less likely to be closed down. Increasing mean age of the workforce and increasing shares of old workers, on the other hand, strongly increase the closure probability. Thus, if plant closure is an indication of technological obsolescence, then an aged workforce can indeed be seen as a characteristic of plants approaching the end of its life cycle.

Both start-ups and closure plants, thus, have distinctive age profiles. Moreover, either type of plants demonstrates rapid changes in their age structure in the year following start-up or preceding closedown (see table 5.3). This implies that the presence of start-ups and closure plants contributes to a variation in age structure that goes beyond the time trends in age structure change that are due to a shifting aggregate age structure of Sweden's working age population.

The picture emerging here is that plant life cycles interact with the ageing of workers in a way that tends to bias estimates of the old worker productivity downwards. It is not very far-fetched to conjecture that this tendency may be reinforced by the selectivity in the closure process. Most closures are probably foreseen and those employees with the best labor market prospects leave at an early stage introducing a negative selection within the age group. For start-ups on the other hand there is uncertainty about the productivity of newly employed people which are predominantly young and the matching process will give a positive selection bias for productivity.

6. Discussion

According to the estimates presented in this paper, there is little need to worry about the productivity consequences of workforce ageing. Although individual performance in many areas peak in young or in prime ages an accumulation of high shares of older adults in manufacturing plants does not seem to have negative effect on plant level productivity. To be more precise, there is no negative effect on average from ageing within the ranges that we empirically observe. On the contrary, when plant level effects are controlled for, high shares of older adults are associated with higher productivity than high shares of young adults. While it is possible that this result holds only for changes in the neighborhood of mean ages around 40 this is well within the relevant range that foreseeable workforce ageing in the developed world will lead to.

A positive effect on productivity of workforce ageing goes against many popular conceptions. Macro-level evidence, however, indicates that a shift from a working-age population dominated by young adults to domination by older workers is indeed positive for economic growth. An early study showing this is (Romer 1987). McMillan and Baesel (1990) for the US and Malmberg (1993) for Sweden also give evidence for positive old workforce effects. Lindh and Malmberg (1999) give evidence for it in an OECD panel while Persson (1998) finds it in Swedish and US regional data. Andersson (2001) presents evidence from Scandinavian time series. Feyrer (2002) and Gómez and Hernández de Cos (2003) are recent working papers arguing the positive effects of an older workforce. A positive relation between workforce ageing and increases in per capita income is also evidenced by how economic development relates to the long-term transformation of the age structure that is associated with the demographic transition (Malmberg and Sommestad 2000). Most of today's highest ranked economies have secured this rank during the decades when population growth was concentrated to the middle-age population. Examples include Germany, Sweden and the US during the early post-war period; Japan in the 1960s, 1970s and 1980s; as well as Korea, Singapore, and Chile in the 1980s and 1990s. In this paper we have been able to show that this macro-pattern may have an underpinning also on the micro-level within manufacturing industry.

A positive relation between workforce ageing and productivity growth also has an implication for the relation between mortality and economic growth. If it was the case that weaker individual level performance during the later parts of working life would exert a downward pressure on firm-level productivity then high mortality among workers above 50 years of age would not necessarily be negative for economic growth. High mortality would have a negative effect on the profitability of educational investment and possibly saving but part of this could be compensated by a weeding out of less-efficient workers. However, in empirical studies increasing longevity has consistent positive effects on per capita income, and this indicates that labor-force ageing is not a process that works against higher productivity unless taken to extremes not generally encountered in the aggregate economy. In fact, as shown in Malmberg and Lindh (2004), a model that takes into account both age structure shifts and changes in longevity can account for much of the global variation in income growth since 1960.

The labor productivity and change in total productivity in a separate plant might, among other factors, depend on the composition of workers and not only on some simple measure of age. If, for example, the prime aged workers are deemed the most productive and the learning-by-doing argument holds, then there might exist some kind of optimal mix of employees. For instance, a certain share of prime aged workers might have to be combined with certain shares of both young and old workers for a plant to achieve its maximum productivity.

A certain share of older workers might influence and enhance the ability to learn by both young and prime-aged workers. This would symbolise a kind of learning-by-seeing or learning-by-interacting relationship between workers of different age groups. But it is apparently not only age that matters, industry or even establishment experience may play a large role in the complicated pattern of labor productivity.

Young workers might also play an important part by introducing new knowledge into the workforce. By our estimates it looks as this group might not have that positive an impact on total labor productivity which might be due to the experience needed to understand how this new knowledge is supposed to raise productivity. It might also be due to prime aged and older workers being stuck in their old working habits unwilling to change the way they go about.

According to our estimates the age composition seems to have a greater influence in larger plants and this might be due to increased interaction and more change of ideas when more people are involved in production. On the other hand, and perhaps even more realistically, it might also be due to larger plants having a greater possibility to achieve its optimal mix of employees, a possibility that might not exist for smaller plants due to many differing restrictions in both hiring and firing.

If corroborated by additional studies, the findings presented in this paper have potentially important policy implications, with special significance for many countries in the European Union. In Europe, since the 1970s, a common measure against unemployment has been early retirement for older workers. The results presented here, on the other hand, indicate that early retirement of older workers may well be detrimental for productivity in already established plants if they are replaced by young adults.

If workforce ageing is good for productivity growth, policies should instead be geared towards finding means to stimulate continued labor-force participation among older workers. Such policies should help employers to design work-practices that take advantage of the services from older workers. Of equal importance is to remove regulations, pension plans and employment contracts that stimulate early retirement. In addition, more focus should be given to factors that can improve the health of people that are approaching older age. Such measures, of course, would be of value not only for their potential to stimulate productivity. Increased labor force participation by people above 55 years of age is also almost a necessity if the fiscal viability of current welfare arrangements is to be preserved when increased longevity greatly increases the population share of people above 65.

If workforce ageing leads to productivity growth, then how should the practice of mandatory retirement in some firms be explained? One possible, but speculative, answer is mortality risks. During the post-war period mortality risks, especially for males, increased fast after 50 years of age. If employees were to be allowed to work indefinitely this would imply that the firm would face a very high risk that some time in the future, at a random date, they would, often without forewarning, irreversibly loose an employee. By introducing mandatory retirement this randomness can, at least partly, be transformed into a deterministic process that may be easier to handle for the management, in particular if it is financed from public PAYG systems. Retirement can occur at a specific, predetermined date not because of a sudden change in productivity but because an undisturbed process of production can, by itself, be essential to the individual plant's performance.

For further research it should be emphasized that our results here also point out several difficulties in estimating the productivity effects of ageing. The age composition and also the educational composition of the workforce is determined in conjunction with technical change and changing demand conditions as well as in the interplay with local factor supplies, in particular local labor markets. We find clear evidence of endogeneity bias and our attempts to solve this by instrumental variables may not be the final word on this issue. The interaction between plant life cycles and the composition of the workforce that we find raise issues about the identification of productivity effects from ageing that fixed effects estimates only can begin to disentangle.

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Table 1.1: Descriptive statistics for the matched employer-employee plant sample over the period 1985-1996.

Variable	Observations	Mean	Std. Dev.	Min	Max
Value added	95 443	78.93	62.91	0.017	2313
Education	95 443	10.95	0.8	9	15
Mean age	95 443	39.61	4.87	23.23	63.57
Employees	95 443	82.80	275	1	12881
Share ≤29	95 443	0.30	0.157	0	0.957
Share 30-49	95 443	0.46	0.137	0	0.955
Share 50≤	95 443	0.24	0.143	0	0.955

Table 2.1: Age share model without plant-level fixed effects, dependent variable log value added per worker.

Dep.var: log VA/empl	(1)	(2)	(3)	(4)
Log share ≤29	0.020	0.006	0.005	0.095
	(5.66)**	(1.77)	(1.30)	(9.26)**
Log share 30-49	0.128	0.080	0.060	0.229
	(20.38)**	(12.91)**	(9.28)**	(10.11)**
Log share 50≤	-0.043	-0.023	-0.016	0.016
	(13.78)**	(7.51)**	(5.08)**	(1.53)
Mean education		0.146	0.133	0.179
		(61.05)**	(49.15)**	(34.30)**
Constant	4.255	2.628	2.728	2.640
	(393.37)**	(91.61)**	(84.86)**	(37.95)**
Plant size restriction			<50	50 or more
Observations	95443	95443	66819	28624
R-squared	0.01	0.05	0.04	0.05

Absolute value of t statistics in parentheses

** significant at 5%; ** significant at 1%*

Table 2.2: Mean age model without plant-level fixed effects, dependent variable log value added per worker.

Dep.var: log VA/empl	(1)	(2)	(3)	(4)
Log mean age	-0.302	-0.075	-0.074	-0.317
	(19.60)**	(4.80)**	(4.28)**	(8.82)**
Mean education		0.151	0.135	0.187
		(62.51)**	(48.70)**	(37.76)**
Constant	5.295	2.807	2.946	3.383
	(93.41)**	(41.07)**	(37.95)**	(23.12)**
Plant size restriction			< 50	50 or more
Observations	95443	95443	66819	28624
R-squared	0.00	0.04	0.04	0.05

Absolute value of t statistics in parentheses
** significant at 5%; ** significant at 1%*

Table 3.1: Age share model with plant-level fixed effects, dependent variable log value added per worker.

Dep.var: log VA/empl	(1)	(2)	(3)	(4)
Log share ≤29	-0.022	-0.021	-0.009	-0.023
	(7.94)**	(7.54)**	(2.90)**	(2.86)**
Log share 30-49	0.039	0.032	0.023	0.138
	(7.21)**	(5.98)**	(4.19)**	(6.72)**
Log share 50≤	0.011	0.012	0.004	0.081
	(4.40)**	(4.69)**	(1.49)	(7.70)**
Mean education		0.098	0.070	0.201
		(29.36)**	(19.23)**	(24.66)**
Plant size restriction			< 50	50 or more
Fixed plant effect	Yes	Yes	Yes	Yes
Observations	95443	95443	66819	28624
R-squared	0.00	0.01	0.01	0.03

Absolute value of t statistics in parentheses
** significant at 5%; ** significant at 1%*

Table 3.2: Mean age model with plant-level fixed effects, dependent variable log value added per worker.

Dep.var: log VA/empl	(1)	(2)	(3)	(4)
Log mean age	0.249	0.262	0.136	0.633
	(13.76)**	(14.58)**	(6.93)**	(14.53)**
Mean education		0.101	0.072	0.202
		(30.28)**	(19.82)**	(24.88)**
Plant size restriction			< 50	50 or more
Fixed plant effect	Yes	Yes	Yes	Yes
Observations	95443	95443	66819	28624
R-squared	0.00	0.01	0.01	0.03

Absolute value of t statistics in parentheses

** significant at 5%; ** significant at 1%*

Table 4.1: Instrumental variables regressions with dependent variable log value added per employee. Shea partial R^2 measures relevance of multivariate instrument model.

Dep. Var: log VA/empl	(1)	(2)	(3)	(4)
Log mean age	1.784	1.662	1.703	2.084
	(12.29)**	(10.79)**	(14.45)**	(12.32)**
Shea partial R^2	0.0256	0.0231		
Partial R^2	0.0673	0.0824		
Education	0.235	0.217	0.156	0.250
	(37.10)**	(28.55)**	(10.59)**	(14.24)**
Shea partial R^2	0.3342	0.2441		
Partial R^2	0.8774	0.8707		
Regime		0.078		-0.070
(=1 if year ≥ 1991)		(8.95)**		(6.49)**
Constant	-4.917	-4.323	-3.755	-6.138
	(8.31)**	(6.79)**	(10.43)**	(8.87)**
Sargan statistic	1.898	2.008		
Sargan p-value	(0.387)	(0.366)		
Fixed plant effect			Yes	Yes
Observations	54006	54006	54006	54006
Number of plant ID			9794	9794
Instruments:				
Lag -2 log share ≤29			x	x
Lag -3 log share ≤29			x	x
Lag -1 log share 30-49	x	x	x	x
Lag -3 log share 30-49				
Lag -3 log share 50≤			x	x
Lag -1 education	x	x	x	x
Lag -2 education	x	x	x	x
Lag -3 education	x	x	x	x

Absolute value of z statistics in parentheses
** significant at 5%; ** significant at 1%*

Table 5.1: Effect on log odds of being a start-up from age and productivity variables, productivity expressed as log value added per worker. Binomial logit models.

Start-up=1	(1)	(2)	(3)	(4)	(5)
Log VA/empl	0.071				
	(3.41)**				
Mean age		-0.072			
		(27.41)**			
Share ≤29			1.558		
			(20.73)**		
Share 30-49				0.596	
				(6.62)**	
Share 50≤					-2.848
					(29.17)**
Constant	-2.811	0.269	-3.000	-2.791	-1.885
	(31.80)**	(2.68)**	(108.59)**	(63.22)**	(81.70)**
Observations	95443	95443	95443	95443	95443

Absolute value of z statistics in parentheses
** significant at 5%; ** significant at 1%*

Table 5.2: Effect on log odds of being a closure plant from age and productivity variables, productivity expressed as log value added per worker. Binomial logit models.

Closure=1	(1)	(2)	(3)	(4)	(5)
Log VA/empl	-0.466				
	(24.35)**				
Mean age		0.031			
		(13.00)**			
Share ≤29			-0.679		
			(8.77)**		
Share 30-49				0.042	
				(0.48)	
Share 50≤					0.745
					(9.20)**
Constant	-0.515	-3.692	-2.239	-2.454	-2.621
	(6.57)**	(37.59)**	(90.13)**	(58.53)**	(109.44)**
Observations	95443	95443	95443	95443	95443

Absolute value of z statistics in parentheses
** significant at 5%; ** significant at 1%*

Table 5.3: Change in age structure in plants after start-up and prior to closure.

	Share ≤29	Share 30-49	Share 50≤	Obs	Mean age
Start Year	0.354	0.468	0.178	1732	37.4
Start (+1)	0.342	0.470	0.188	1732	37.8
Start (+2)	0.331	0.474	0.195	1732	38.1
Start (+3)	0.319	0.475	0.205	1732	38.5
Start (+4)	0.306	0.477	0.217	1732	38.9
Last (-4)	0.301	0.447	0.252	3200	39.7
Last (-3)	0.295	0.446	0.260	3200	40.0
Last (-2)	0.289	0.447	0.264	3200	40.3
Last (-1)	0.274	0.449	0.277	3200	40.8
Last Year	0.256	0.454	0.290	3200	41.4

Technical Appendix

I. Introduction

This appendix offers information on the dataset, variables, estimation techniques, model specifications and results. The appendix is organized as follows. Section II provides information on the data and the definition of variables. Section III presents details on the specification and estimation of the statistical models.

The statistical program used for the analysis in this paper is Stata/SE 9.1 with the add-on program "Instrumental variables and GMM: Estimation and testing" by Baum, Schaffer and Stillman (2003), distributed as st0030 & st0030_1. This program includes an extended instrumental variable regression command (ivreg2), overspecification tests (overid), heteroskedasticity tests (ivhettest), and an endogenity test (ivendog).

II. The Industrial Statistics dataset

The data used in the paper is a merged employer-employee dataset from Statistics Sweden. Its two parts are made up of, on the one hand, a survey based set of data on plant specific information, and on the other hand, registry based labor market statistics that enables the connection between individuals and their work place. This data set provides us with the possibility to describe establishments by the characteristics of their employees such as age, education, gender and dwelling.

The two statistical sources from which the dataset used in our analysis is made up are RAMS (1985-1996), previously known as ÅRSYS, a register based source of labor market statistics, and the Swedish Manufacturing and Mining Survey (1970-1996), an industrial source of plant level statistics. By matching these two sources we are able to analyse the influence of certain employee characteristics on productivity for plants from different industrial sectors. The merging procedure is quite complicated and the employees do not match the plants in a perfect manner, both some establishments and some potential employees are left out, but the resulting dataset comprises of most of the employment and in particular the larger plants.

The Swedish Manufacturing and Mining Survey, from here SMMS, consists of plant data from somewhere in between 9000 and 12000 establishments, depending on the year, while RAMS consists of individual data for around 550000-750000 individuals yearly. After merging the data sources we end up with around 8000-9000 establishments in each year, with a quite stable average of around 80 employees per plant for the years 1985-1996.

The number of observations in our specifications differ depending on the adjustments made prior to or during estimation. Introducing lags and correcting for missing values affects the size of the sample used. Therefore the number of observations varies quite substantially between, for example, the complete sample and the sample used when the endogenous variables are instrumented. In the complete sample there are a total of approximately 95000 observations (plants observed in a specific year) while in the dataset available using IV-regression there is only around 55000 predicted observations left since the predictions use lags of variables up to three years back.

The education variable used in the regressions is made up of an approximation of the time spend in schooling by the employed. For the majority of the individuals in the data we have information on their highest level of schooling and on what their major subject was when studying. The levels are split into primary, secondary and tertiary education, and from this information we have created the education variable by assuming that primary equals 9 years of schooling, secondary equals 12 years, and tertiary equals 15 years. The plant average years of education are thereafter corrected for the individuals missing educational information.

The mean age variable is based on the five-year age group that an individual belongs to, for example, 20-24 year olds or 50-54 year olds. When aggregating this variable we have simply assumed that the individuals are equally distributed within these five-year age groups. Assuming this we are able to calculate the mean age of the persons employed in each and every plant in each and every year analysed.

The number of employees working in each plant or firm can be extracted from both the SMMS and for RAMS, but they differ in some senses. Most of the difference is to our knowledge due to differing measurement routines. While SMMS gives an average yearly number of employees RAMS gives a point estimate in time of the number of workers employed. For the regression analysis we use the number of employees according to the SMMS, since this data is related to and measured over the same period as the data on productivity, therefore making the transformation to average worker productivity more likely to be correct.

Merging of the datasets is not completely unproblematic and both some plants and some individuals fall out of the sample being used for estimation. When it comes to the plants from the SMMS around 90 percent of them are still in the sample after adjustments are made and the same is more or less true also when it comes to individual characteristics. Here we have to separate between individuals and individual characteristics since the number of individuals working in each plant is taken from the SMMS and the characteristics are taken from RAMS. Thus, it is assumed that the distribution of the average characteristics from RAMS is identical to the distribution in the average number employed according to the SMMS. For obvious reasons this is likely to be a better approximation for larger plants.

Table A1-A3 display some descriptive statistics for the samples used in the analysis. A1 shows the statistics for the full sample (also reported in the paper in table 1.1) and A2 shows the same statistics when using the number of employees as importance weights. A3 shows the statistics for the variables used in the instrumental variable estimations presented in the results part of the paper. Value added, education and mean age are all expressed as averages, education and mean age in years, and value added as thousands of SEK per worker in 1968 constant producer prices.

Table A1: Descriptive statistics for sample used in OLS regressions

Variable	Obs.	Mean	Std. Dev.	Min	Max
Value added	95443	78,93	62,91	0,017	2313
Education	95443	10,95	0,8	9	15
Mean age	95443	39,61	4,87	23,23	63,57
Employees	95443	82,80	275	1	12881
Share -29	95443	0,30	0,157	0	0,957
Share 30-49	95443	0,46	0,137	0	0,955
Share 50-	95443	0,24	0,143	0	0,955

Table A2: Descriptive statistics using number of employees as importance weight

Variable	Obs.	Weight	Mean	Std. Dev.	Min	Max
Value added	95443	7902890	93,49	73,93	0,017	2313
Education	95443	7902890	11,18	0,75	9	15
Mean age	95443	7902890	39,62	3,575	23,23	63,57
Employees	95443	7902890	995,11	1920	1	12881
Share -29	95443	7902890	0,28	0,120	0	0,957
Share 30-49	95443	7902890	0,48	0,090	0	0,955
Share 50-	95443	7902890	0,24	0,096	0	0,955

Table A3: Descriptive statistics for sample used in IV-regressions

Variable	Obs	Mean	Std. Dev.	Min	Max
Value added	54006	82,18	61,33	0,03	1637,28
Education	54006	10,98	0,73	9	15
Mean age	54006	40,08	4,57	24,94	63,57
Employees	54006	96,07	300	1	12881

Table A4 shows the yearly statistics of our complete sample after merging our two data sources and making some initial adjustments to achieve a data set suitable for estimation. During the period analysed some apparent trends in the data can be seen in these figures. First, the workforce is getting older and this is especially due to the youngest workers decreasing substantially as part to the total number of employees. This is mostly due to a generally increased length of education in the inflow to the labor market as compared to the outflow and for these industries also to the fact that young workers were selectively fired during the severe economic downturn of the 1990s. Second, the mean level of education is rising. Explanations for this includes, as mentioned above, increased length of education, older workers with low education retiring, and persons with low education getting laid off to a higher degree during the crisis. Third, the number of establishments and especially the number of employees is decreasing. Table A5 compares the original datasets with both each other and with the complete sample achieved after merging and adjusting. Around 90 percent of both individuals and establishments are still a part of the material being used for estimation, making the loss of observations quite small. The datasets do not match completely in the number of individuals supposedly being employed in the Swedish mining and manufacturing industries but the discrepancy is, as can be seen, not very large.

Table A4: Yearly statistics of the total sample available after merging and initial adjustments

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Value added	62,7	64,6	67,3	69,6	72,5	77,7	80,5	86,7	91,3	95,0	92,9	93,6
Wage	22,1	22,7	23,3	23,6	24,1	26,2	27,9	30,2	30,0	29,9	29,5	31,2
Employees	85,8	85,8	86,1	85,9	83,8	87,2	82,9	80,2	79,8	78,2	78,8	77,1
Education	10,5	10,6	10,7	10,7	10,8	11,0	11,0	11,1	11,2	11,2	11,3	11,3
Mean age	39,4	39,3	39,2	39,1	39,1	38,8	39,4	40,2	40,5	40,2	40,0	40,4
Age -29	31%	31%	31%	32%	32%	32%	30%	27%	26%	27%	27%	26%
Age 30-49	45%	45%	45%	45%	45%	45%	46%	48%	49%	48%	47%	48%
Age 50-	25%	24%	24%	24%	24%	22%	23%	25%	25%	25%	25%	26%
Primary education	50%	48%	46%	45%	43%	42%	41%	40%	38%	36%	35%	34%
Secondary education	38%	40%	42%	43%	43%	49%	50%	50%	50%	52%	53%	54%
Tertiary education	5%	5%	5%	6%	6%	8%	9%	10%	11%	11%	11%	12%
Unknown/missing education	7%	7%	7%	7%	7%	1%	1%	1%	1%	1%	1%	1%
Total employed (thousands)	716	716	720	717	714	717	663	610	560	568	599	602
Establishments	8350	8352	8365	8337	8523	8222	7999	7598	7025	7263	7601	7808

Value added and wage expressed as average per employed thousands of SEK per employee deflated by 1968 producer price index. Employees, education and mean age expressed as establishment means. Age and education shares in percentage of total persons employed. Establishments meaning the number of specific plants, including one or more businesses, being part of the mining and manufacturing sector.

Table A5: Comparison between original statistical sources and the total sample available for regression analysis

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Plants in SMMS	9348	9276	9253	9230	9286	9408	9135	8629	7881	8006	8285	8506
Plants in sample	8350	8352	8365	8337	8523	8222	7999	7598	7025	7263	7601	7808
Share	89%	90%	90%	90%	92%	87%	88%	88%	89%	91%	92%	92%
Individuals in RAMS	743	748	759	767	759	723	687	615	557	592	620	616
Employed in sample	694	703	710	714	717	687	645	593	535	562	594	588
Share from RAMS	93%	94%	94%	93%	95%	95%	94%	96%	96%	95%	96%	96%
Employed in SMMS	780	778	776	767	759	782	720	645	590	600	634	638
Employed in sample	716	716	720	717	714	717	663	610	560	568	599	602
Share from SMMS	92%	92%	93%	93%	94%	92%	92%	95%	95%	95%	95%	94%

Number of persons employed differing between the two statistical sources used in creating the dataset used for estimation. Share from data source is the percentage of individuals and establishment not being excluded during the matching and adjusting procedure.

III. Specification and estimation

The variables used in our presented analysis are age groups, education, mean age, productivity, number of employed, and producer price indices. We have also experimented with using wages, hours worked, education groups, regional information, industry sector, machinery investments, building investments and IT-capital share as independent variables in order to test the stability of our models. These estimations are not presented in the paper but the results did not change much when introducing these different variables. One other technique possible to apply to the data is to de-mean the data using the industry sector division as the group variable. This is also something that has been tested for on this dataset prior to our current analysis. The intuition for using this technique is that the use of time variables to correct for business cycle fluctuation does not fit all different industry sectors equally well since there are parts of the economy both lagging and leading the aggregated movements. Applying this approach, on the other hand, does not change the results in any unexpected manner either.

For our estimations the employees of an establishment is normally split up into the age groups 16-29, 30-49 and 50-. The reason behind this separation is twofold, first, introducing more age groups increases the problem of collinearity among the regressors, and second, this separation more or less marks different stages in the individual life cycle. The young workers are generally healthy individuals, mostly without overwhelming family responsibilities, with good learning abilities, higher average education and greater mobility, which is expected to increase the efficiency of the labour market. The middle-aged workers are in most cases family providers, having many different responsibilities, but also having experience and still being healthy in general. The older workers have a great deal of experience and job-related smartness, they know how to be productive without exhausting themselves too much, but their health is in general weakening and they are not as strong or able to learn as fast as they once were. The task in our paper has mostly been to try to figure out the influence of the different age groups on the plant specific productivity when controlling for different variables.

In our analysis we use ordinary linear regression techniques, fixed effect panel estimation, and also instrumental variable estimation. The results from the OLS and fixed effects estimations are in general quite robust, but to a high degree influenced by collinearity among the independent variables, which makes the coefficient estimates rather imprecise. Except for collinearity we are also concerned with the possible endogeneity of the variables included in our specifications. In trying to overcome these problems we have invoked instrumental variable estimation as the technique of choice. When it comes to instrumental variable estimation the technique is highly dependent on the quality of instruments available. In our case using the dataset at hand we do not have a lot to choose from and are therefore mostly restricted to using lags of the endogenous variables being instrumented. This, of course, limits our possibilities to find good specifications and strong instruments, but as a test for the validity of the prior regressions we still find it useful to include this approach.

Using lags of the endogenous variables turned out to be quite problematic both due to instrument weakness and to problems involving overspecification of the models tested for. The same problems found in the ordinary least squares specification seem to affect the instrumental variable estimations in a similar way. Collinearity still appears to be a major problem influencing the coefficients and making the interpretation of the results quite uncertain. The problem is clearly more influential when it comes to trying to instrument age shares than the mean age variable. The age share specifications do not prove to be anywhere near to robust and the weakness of the instruments, especially when it comes to the test statistics, is quite obvious.

When estimating the influence of age and education on productivity with instrumental variable techniques in Stata one has to de-mean the variables to be able to use the tests required for specification evaluation. But the demeaning procedure becomes quite complex when it involves many different lags forcing some approximations and therefore we have also estimated the models using the XTIV commands in which the program itself takes care of the transformation of the variables. Since there are no tests available for the XTIV routine all the test statistics is based on regressions using demeaned variables. This approach creates some uncertainty regarding the test statistics of the regressions presented, but since the difference between the two sets of estimates is very small we accept the tests as being close to identical for both approaches.

In order to be useful an instrumental variable must satisfy two requirements: it must be correlated with the included endogenous variables, and orthogonal to the error process. The former condition may be readily tested by examining the fit of the first stage regressions. The first stage regressions are reduced form regressions of the endogenous variables on the full set of instruments. The relevant test statistics here relate to the explanatory power of the excluded instruments in the regressions. The statistics used here is the R^2 of the first-stage regression with the included instruments "partialled-out", therefore, the partial R^2-measure (see for example Bound et. al., 1995).

When multiple endogenous regressors are used the F-statistics and partial R^2-measures from the first-stage regressions will not reveal instrument weakness and other statistics are required. One such statistic proposed by Shea (1997) is a partial R^2 measure that takes the intercorrelations among the instruments into account. For a model containing a single endogenous regressor, the two R^2 measures are equivalent. As a rule of thumb for models with multiple endogenous regressors, if an estimated equation yields a large value of the standard partial R^2 measure and a small value of the Shea measure, one may conclude that the instruments lack sufficient relevance to explain all the endogenous regressors, and the model may be essentially underidentified. The measure can be expressed as:

$$R_p^2 = \frac{v_{i,i}^{OLS}}{v_{i,i}^{IV}} \left[\frac{(1 - R_{IV}^2)}{(1 - R_{OLS}^2} \right]$$

where $v_{i,i}$ is the estimated asymptotic variance of the coefficient (see Godfrey, 1999, for more information)

If the instruments seem satisfy the two requirements and the Shea measure is not too small one can go on and test the statistics of the second-stage regression. The test statistics used for evaluation and acceptance of the IV-regressions are the Sargan's (1958) test of overidentifying restrictions for regressions estimated via instrumental variables, in which the number of instruments exceeds the number of regressors, also known as an overidentified equation. This is a test of the joint null hypothesis that the excluded instruments are valid instruments by being uncorrelated with the error term and correctly excluded from the estimated equation.

In the context of GMM, the overidentifying restrictions may be tested via the commonly employed *J* statistics of Hansen (1982). This statistics is the value of the GMM objective function

$$J(\hat{\beta}) = n\,\bar{g}(\hat{\beta}) W \,\bar{g}(\hat{\beta}),$$

where *W* is an *L*L* weighting matrix, evaluated at the efficient GMM estimator

$$\hat{\beta}_{EGMM} = (X'ZS^{-1}Z'X =)^{-1} X'ZS^{-1}Z'y .$$

The efficient GMM estimator is the estimator with an optimal *W*, one which minimizes the asymptotic variance of the estimator, and achieved by choosing $W = S^{-1}$. Therefore, under the null the *J* statistics become

$$J(\hat{\beta}_{EGMM}) = n\,\bar{g}(\hat{\beta})'\hat{S}^{-1}\,\bar{g}(\hat{\beta}) \overset{A}{\sim} \chi^2_{L-K} .$$

In the case of heteroskedastic errors, the matrix $\hat{S}$ is estimated using the diagonal matrix of squared residuals where $\hat{u}_i$ is a constant estimate of u_i, and the J statistics becomes

$$J(\hat{\beta}_{EGMM}) = \hat{u}\,Z'(Z'\hat{\Omega}Z)^{-1} Z\,\hat{u}' \overset{A}{\sim} \chi^2_{L-K}$$

The *J* statistics is distributed as χ^2 with degrees of freedom equal to the number of overidentifying restrictions *L-K* rather than the total number of moment conditions *L* because, in effect, *K* degrees of freedom are used up in estimating the coefficients of β. Sargan's statistics is a special case of Hansen's *J* under the assumption of conditional homoskedasticity. Thus if we use the IV optimal weighting matrix together with the expression for *J*, we obtain

$$\text{Sargan's statistic } = \frac{1}{\hat{\sigma}^2}\hat{u}'Z(Z'Z)^{-1}Z'\hat{u} = \frac{\hat{u}'Z(Z'Z)^{-1}Z'\hat{u}}{\hat{u}'\hat{u}/n} = \frac{\hat{u}'P_z\,\hat{u}}{\hat{u}'\hat{u}/n}$$

The Sargan's statistic has an nR_u^2 form, where R_u^2 is the uncentered R^2, and can be calculated by regressing the IV equation's residuals upon all instruments Z, both the included exogenous variables and those instruments which do not appear in the equation. A rejection of the null hypothesis implies that the instruments are not satisfying the orthogonality conditions required for their employment. This may be either because they are not truly exogenous, or because they are being incorrectly excluded from the regression.

From Table A6, using the age share variables, it is obvious that the instruments are very weak when it comes to the combined estimation. In some specifications using age shares the partial R^2 values for the separate first-stage are quite high, as in Table A6 specification 3, but turning to Shea partial R^2 all of the specifications display very low instrument strength. Also the coefficients in the different specifications vary quite substantially and are definitely not as robust as when using the mean age variable. Because of these facts we have concluded that the age share specifications are not robust enough in examining the effect of aging on productivity. Note, however, that the basic hump shape is preserved in the point estimates, and so is the tilt of the hump towards more positive old worker effects as we control for fixed plant-specific effects.

Table A7 shows the mean age regressions when using de-meaned variables in order for Stata to produce test statistics. The coefficient estimates differ somewhat from the fixed effects (XTIV) estimation reported in table 4.1, even if the specification setups are identical in some of the models. This problem arises due to the complicating procedure of de-meaning when using and unbalanced panel with lagged variables. Here we have also included some further specifications in order to show the robustness of the estimated coefficients. Shea's statistics for the regressions is still quite weak, but much higher than in the age share specifications. Sargan's test statistics are very comforting showing no complications when it comes to the issue of overspecification.

Table A6: Sample of instrumental variable regressions using age shares

Log value added	1	2	3	4	5	6
Log share -29	0.442	0.440	0.549	-0.480	-0.394	-0.504
	(3.79)**	(4.52)**	(4.94)**	(6.87)**	(5.32)**	(7.08)**
Shea partial R^2	0.0023	0.0031	0.0027	0.0037	0.0031	0.0037
Partial R^2	0.3983	0.3477	0.3495	0.0451	0.0129	0.0194
Log share 30-49	1.313	1.163	1.507	-0.021	0.033	-0.021
	(4.15)**	(4.51)**	(5.07)**	(0.18)	(0.29)	(0.18)
Shea partial R^2	0.0011	0.0016	0.0014	0.0069	0.0064	0.0069
Partial R^2	0.1434	0.1146	0.1137	0.0224	0.0158	0.0152
Log share 50-	0.290	0.244	0.344	-0.187	-0.156	-0.182
	(3.30)**	(3.37)**	(4.12)**	(2.80)**	(2.42)*	(2.69)**
Shea partial R^2	0.0037	0.0050	0.0044	0.0047	0.0048	0.0048
Partial R^2	0.5047	0.5036	0.5031	0.0341	0.0186	0.0212
Education	0.119	0.080	0.084	0.114	0.113	0.140
	(10.78)**	(8.10)**	(7.80)**	(6.61)**	(6.18)**	(7.98)**
Shea partial R^2	0.1283	0.1608	0.1561	0.1284	0.1297	0.1462
Partial R^2	0.8774	0.8684	0.8707	0.2663	0.1516	0.1853
Regime			0.165			-0.021
			(24.92)**			(3.35)**
dum1989		0.022			0.017	
		(2.07)*			(3.02)**	
dum1990		0.090			0.025	
		(7.77)**			(3.93)**	
dum1991		0.097			-0.006	
		(8.67)**			(0.84)	
dum1992		0.143			-0.017	
		(12.45)**			(2.00)*	
dum1993		0.193			-0.007	
		(16.59)**			(0.66)	
dum1994		0.276			0.046	
		(22.38)**			(4.67)**	
dum1995		0.266			0.037	
		(21.26)**			(3.64)**	
dum1996		0.273			0.013	
		(20.84)**			(1.11)	
Constant	4.997	5.094	5.661	0.000	-0.012	0.013
	(7.69)**	(9.45)**	(9.21)**	(0.03)	(1.94)	(3.13)**
Sargan statistic	0.326	0.821	0.538	2.230	1.811	1.446
Sargan p-value	0.84970	0.66327	0.76433	0.52608	0.61252	0.69487
Fixed effect				Yes	Yes	Yes
Observations	54006	54006	54006	54006	54006	54006
Estimation style	IV	IV	IV	IV	IV	IV
Instruments						
L2 log share -29	x			x	x	x
L3 log share -29		x	x			
L1 log mean age	x	x	x			
L3 log share 30-49				x	x	x
L2 log share 50-	x	x	x	x	x	x
L3 log share 50-				x	x	x
L1 education	x	x	x	x	x	x
L2 education	x	x	x	x	x	x
L3 education	x	x	x	x	x	x

Absolute value of z statistics in parentheses
* significant at 5%; ** significant at 1%

Table A7: Mean age regressions using de-meaned variables with Shea and Sargan statistics.

Log value added	1	2	3	4	5	6
Log mean age	1.688	1.691	1.915	1.918	1.564	1.562
	(15.79)**	(15.93)**	(14.17)**	(14.33)**	(10.08)**	(10.16)**
Shea partial R^2	0.0625	0.0634	0.0478	0.0487	0.0367	0.0374
Partial R^2	0.0976	0.0989	0.0467	0.0476	0.0371	0.0377
Education	0.157	0.157	0.209	0.209	0.181	0.181
	(11.84)**	(11.84)**	(15.22)**	(15.23)**	(11.39)**	(11.39)**
Shea partial R^2	0.1707	0.1711	0.1901	0.1902	0.1500	0.1503
Partial R^2	0.2668	0.2670	0.1858	0.1859	0.1518	0.1518
Regime			-0.040	-0.040		
			(6.40)**	(6.46)**		
dum1989					0.006	0.006
					(1.12)	(1.13)
dum1990					0.003	0.003
					(0.55)	(0.56)
dum1991					-0.035	-0.034
					(4.90)**	(4.91)**
dum1992					-0.044	-0.044
					(4.87)**	(4.88)**
dum1993					-0.033	-0.033
					(3.24)**	(3.25)**
dum1994					0.022	0.022
					(2.18)*	(2.20)*
dum1995					0.000	0.000
					(0.01)	(0.03)
dum1996					-0.020	-0.020
					(1.72)	(1.72)
Constant	-0.000	-0.000	0.025	0.025	0.010	0.010
	(0.01)	(0.01)	(6.04)**	(6.09)**	(1.60)	(1.60)
Sargan statistic	1.131	1.188	1.654	1.673	2.816	2.829
Sargan p-value	(0.88937)	(0.94606)	(0.79907)	(0.89224)	(0.58911)	(0.72628)
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	54006	54006	54006	54006	54006	54006
Number of plant ID						
Estimation style	IV	IV	IV	IV	IV	IV
Instruments						
L2 log share -29	x	x	x	x	x	x
L3 log share -29	x	x	x	x	x	x
L1 log share 30-49	x	x	x	x	x	x
L3 log share 30-49						
L3 log share 50-		x		x		x
L1 education	x	x	x	x	x	x
L2 education	x	x	x	x	x	x
L3 education	x	x	x	x	x	x

Absolute value of z statistics in parentheses
* significant at 5%; ** significant at 1%

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