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COORDINATION AND SPILLOVERS

BY

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ABSTRACT

In a model with positive productive spillovers I estimate the production losses caused by the agents' inability to match perfectly with one another. When there are positive spillovers to physical or human capital, when agents differ in their endowments of such capital, and when trading coordination is imperfect, the market sector will tend to be larger than optimal, and market participation should be taxed. Surprisingly, a perfectly coordinated economy in which agents' locations reflect the nature of the spillovers can yield a level of GNP up to nine times as large as an economy in which agents locate at random. The estimates are rough, but the bottom line is clear: Coordination makes a big difference to per capita GNP, and cross-country differences in how well activities are coordinated could perhaps explain a large portion of cross-country inequality. Similarly, secular changes in organization might explain a large portion of the change in the Solow residual in one country over time.

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1. Introduction.

Positive external effects have been found to pervade several major types of economic activity.[1] These include research and development spending, investment in human capital, and the provision of intermediate goods. The scope of these external effects differs, of course, depending on the context. Some technical knowledge spills over country borders. Other knowledge is shared only among people who are in close working contact with one another, and spillovers there will be local in nature. The scope of the external effects of an activity will generally also depend on whether this activity is being carried out in proximity to those who can benefit from it. Thus we expect more spillovers in cities than elsewhere.

In spite of the great diversity of activities and the many different locations in which they are being carried out, I shall assume a "representative spillover", a positive spillover of uniform scope. My framework resembles that of Lucas (1988, 1990), in that the size of the productive spillover depends on how much human capital agents have. But while Lucas deals only with a representative agent, I assume that agents differ in their endowments of human capital. This gives rise to an assignment problem, the problem of how to match agents to each other so as to maximize the benefits from the spillovers they bestow on each other. This paper will analyze three ways in which this assignment problem might be solved, and compares the levels of welfare that arise in each case.

In situations involving positive spillovers among large numbers of people, the usual theoretical outcome is that too little effort is spent on these

[1] Evidence includes Summers and Wolfe (1977), Scherer (1984), Jaffe (1986), Bartelsman et al (1991), Caballero and Lyons (1991), Rauch (1991), and Wolff and Nadiri (1991). See the recent survey by Griliches (1991).

activities (Diamond 1982, Mortensen 1982, Lucas 1988, Romer 1990, Rustichini and Schmitz 1991). These results hold when agents do not differ in the quality of ideas, skills, or goods that they bring to market. I will show, however, that when markets are incomplete and trading partners are chosen partly at random, a countervailing force is at work: too many low quality goods and services enter the market, and equilibrium activity exceeds its efficient level. The reason for this is adverse selection: the marginal market entrant is below average. His decision to enter lowers the average quality in the market, and since he ignores this, the market is too large. In contrast to the adverse selection models of Akerlof (1970) and Weiss (1980), the marginal participant is the worst one, not the best one, and this leads to the result.

In contexts such as the original used car example it is indeed likely that the marginal participant offers the best good or service. In the macro context, however, the opposite is probably the rule: the best investment projects and the best ideas get implemented, and the best workers enter the labor market. One way to identify the marginal entrants is to see who responds the most to cyclical fluctuations. Among firms it is the low profit producers who exit or go bankrupt during recessions, while among workers it is those with low wages that bear the brunt of cyclical employment changes.[2]

Others have already looked at participation decisions when traders' goods or services differ in quality. Akerlof (1969) assumes that production needs homogenous capital to work with heterogenous labor. Lucas (1978) divides the labor force into homogenous workers and heterogenous management who work with each other and with homogenous capital to produce output. In both models,

[2] See Keane, Moffitt and Runkle (1988) and Kydland and Prescott (1989) for evidence on this point.

equilibrium maximizes output and is hence Pareto optimal. Sattinger (1975) and Becker (1980) study how two homogeneous populations should be assigned to each other so as to maximize aggregate output.

The paper will analyze the two opposite extremes. The next section takes up the case in which assignments are purely random. Section 3, a variation on the models of Sattinger (1975), Becker (1980) and Kremer (1991), looks at a perfectly coordinated competitive equilibrium in an environment with complete information about agents' endowments -- an ideal state at which output is at a maximum. Finally, section 4 makes two welfare calculations; the first compares aggregate output to the second-best output level in which meetings are still random; the second compares it to output in competitive equilibrium. The first welfare gain ranges from 3.5% and 30%, while the second is somewhere between 43% and a staggering 900% -- both sets of measures depending on the strength of the spillover. The first type of welfare gain is attainable by taxing participation; the second is not since it assumes more information than is actually there.

The numbers 43%-900% are probably overestimates. But they are an order of magnitude larger than the 6%-9% of GNP estimate for the value of "job-match" information that Jovanovic and Moffitt (1990) recently derived.[3] This suggests* that whatever information people accumulate as a result of their market experience is but a small fraction of the universe of productively useful information; it also suggests that coordination may be an important explanation for cross-country or secular within-country differences in the Solow residual.

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[3] However, this estimate did not include the value of information that results in improved assignments of people to tasks or teams within firms. This is Prescott's and Visscher's (1980) concept of organization capital.

2. Imperfectly Coordinated Meetings.

This section will analyze uncoordinated assignments or meetings among agents with different endowments. In this scheme, each trader will meet n other traders for sure, but he can not choose or even foresee his partners' types. Thus I replace the thick market externality of the congestion type, by an Akerlof-type contamination externality in the meeting process.

An agent of type x can produce[4] $f(x, y_1, \ldots, y_n)$ when his nearest n neighbors are of types $y_1, \ldots, y_n$. Only the nearest neighbors matter. The

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[4] A special case of this formulation is the production function that Lucas (1988) uses, in which the external effect enters through the population mean, or more generally through the distribution of all participants' characteristics. For instance let

$$f_n(x, y_1, \ldots, y_n) = Ax\left(\frac{1}{n}\sum_{i=1}^{n} y_i\right)^{\gamma}.$$

Then if neighbors are chosen randomly, and if the neighborhood is allowed to expand, we get

$$\lim_{n \to \infty} f_n(x, y_1, \ldots, y_n) = Axh^{\gamma} \qquad \text{almost surely},$$

where h is the mean of x in the population of participants. More generally let $f(x, y_1, \ldots, y_n) = f(x, \nu_n)$, where ν_n is the measure of y among x's n neighbors. Again under random choice of neighbors, ν_n almost surely converges to ν, the population distribution among all participants, and except in some knife-edge cases discussed in Jovanovic (1987), $f(x, \nu_n)$ converges almost surely to $f(x, \nu)$, so long as f is continuous in its second argument.

To derive this limiting case, I assumed that people form groups randomly. A different, more directed assignment rule would have led to a different limiting functional form. This brings out the general point that an output equation of the type $f(x, \nu)$ is really a reduced form, not a structural relation. The missing structural relation is, of course, the assignment rule itself, or rather the level of information that the assignment rule can depend on. Only in the unlikely additively separable case in which

$$f_n(x, y_1, \ldots, y_n) = f_0(x) + \sum_{i=1}^{n} f_1(y_i, n)$$

can one aggregate f over people to obtain a relation that is invariant to assignment rules used to match agents to one another. Moreover, this invariance holds only in the <u>limit</u>: $f(x, \nu) \equiv f_0(x) + \lim_{n\to\infty} \sum_i \int f_1(y, n)\, d\nu(y)$. For finite n, the distribution of f will still depend on the assignment rule.

space of locations may be geographical, in which case one can imagine a collection of islands each of which has $n + 1$ people on it.[5] Then $y_1, \ldots, y_n$ may be the level of human capital among the island's inhabitants. Or, one can think of the space of locations as the spectrum of possible technological choices or R&D activity.[6] Then $y_1, \ldots, y_n$ may denote the quality of the research output of a firm's n closest technological neighbors.

The agent's cost of participating in the market is $c(x)$. Staying out gives him a payoff of zero. The distribution of types has CDF $G(x)$ and density $g(x)$. If agent x goes in, he expects his nearest neighbors to be randomly chosen participants. So if he knows that all types $x \epsilon A$ will go in, his expected output is

$$q(x;A) \equiv \left(\int_A dG(y)\right)^{-n} \int_A f(x, y_1, \ldots y_n)\, dG(y_1), \ldots dG(y_n) \ .$$

A risk-neutral agent of type x will therefore go in if $q(x;A)$ exceeds $c(x)$. So Equilibrium is a set A^0 that "self-fulfills":

$$A^0 = \{ x \in R \,|\, q(x;A^0) > c(x) \}.$$

On the other hand, under the constraint that one's neighbors are assigned randomly, the aggregate output maximizing set A* solves

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[5] A strand of literature in Public Finance is very much concerned with spillovers in geographical space; the spillovers being peer-group effects in schooling. See de Bartolome (1990).

[6] This is the space that Jaffee (1986) deals with. See hid first equation for how measures of technological change.

$$\underset{A}{\operatorname{argmax}} \int_A [q(x;A) - c(x)]dG(x).$$

If redistribution were costless, A^* would be the socially optimal set of participants.

The restriction that one's neighbors are a random sample of participants is unrealistic. Businesses and people do not locate at random locations, but in communities whose structure seems designed to take advantage of the benefits that agents can bestow one another. This static framework is appropriate if agents' characteristics are highly unstable over time, or if assignments are permanent. Since neither of these conditions seems to hold in practice, one would expect a gradual improvement in the quality of assignments,[7] so that these would start to resemble the competitive equilibrium assignment described in the next section. This process would mitigate the forces I am about to describe, but it would not eliminate them.

Let us resume by assuming that x is quality, say the level of human capital, and that it is better to have high quality neighbors. Then f is

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[7] As, for instance, in the process described in Jovanovic (1979), where an agent learns gradually but imperfectly about the location of his best job match, or the process described in Prescott and Visscher (1980) in which the agent and his firm learn gradually about the task to which the worker should be assigned.

increasing in all its arguments.[8] Further, people's market returns probably differ far more than their non-market returns, and so, as a first approximation, let $c(x) = c$ for all x. Equilibrium will now have the better agents entering the market and the worse ones staying out. Let z be the quality of the marginal entrant, and let $m(x,z) \equiv q(x;\{(z,\infty)\})$ so that

$$m(x,z) = \left(1 - G(z)\right)^{-n} \int_z^\infty f(x,y_1,\ldots,y_n)\,dG(y_1),\ldots dG(y_n) .$$

Then equilibrium is a number z^0 such that[9]

$$m(z^0,z^0) = c .$$

Since f is increasing, $dm(z,z)/dz > 0$, and z^0 is unique.

For the planner, $A^* = (z^*,\infty)$, and z^* solves

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[8] This seemingly inocuous assumption is in fact questionable. Having a high-quality neighbor may lower one's productive costs (a positive nonpecuniary spillover), but it may also lower one's profits if neighbors compete among themselves (a negative pecuniary spillover). See Jaffee (1986) for a careful empirical distinction between these two effects.

I will sidestep this problem by assuming that goods are supplied competitively so that there is no monopoly power. In this case the effect that one's neighbors has on f consists only of the direct production spillover; their effect on the product price is negligible since relative to all suppliers they are of measure zero. If the competitive assumption is in fact unwarranted, it leads to a bias in the empirical work in section 4. But the direction of the bias is unclear. On the one hand, Jaffee (1986, Tables 3, 4 and 5) estimates that the pecuniary spillovers are negative. But others (e.g. Murphy et al, 1989) argue that the pecunairy spillover is in fact positive.

[9] This is an "interior" equilibrium. For it to exist it is enough that $f(x_{min},y) < c$, and that $f(x_{max}, y) > c$ for all n-vectors y. These restrictions will be met if market skills vary enough.

$$\max_{z} \int_{z}^{\infty} [m(x,z) - c] dG(x) .$$

Optimality of z^* requires that[10]

$$m(z^*, z^*) = c + \frac{1}{g(z^*)} \int_{z^*}^{\infty} m_2(x, z^*) dG(x) .$$

Since m_2 is positive,[11] $m(z, z)$ is therefore an increasing function. Figure 1 shows that equilibrium is unique, and that the planner would prefer the market to be smaller. That is, he wants a higher z. How <u>much</u> higher will depend on the size of m_2, and this quantity will be higher in societies where the distribution of x is uneven. As note 7 shows, the size of m_2 depends on the difference between agent x's output when encountering a set of representative entrants, $m(x, z)$, and his output when meeting a set of marginal entrants, $f(x, z, \ldots, z)$.

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[10] A subscript will denote a partial derivative, while for a total derivative we shall use a prime.

[11] This is because f is increasing in $(y_1, \ldots, y_n)$, and because

$$m_2(x, z) = h(z)[nm(x,z) - \sum_{i=1}^{n} \hat{f}^i(x,z)]$$

where h is the hazard rate of G, and where

$\hat{f}^i(x,z) = \underset{y_{-i}}{E} \{f(x, y_1, \ldots y_{i-1}, z, y_{i+1}, \ldots, y_n) | y_j \geq z, \ j \neq i\}$. Since f is increasing in each of the y_i, $m(x, z) > \hat{f}^i(x, z)$ for all i, and so m_2 is positive. If f were decreasing in $(y_1, \ldots, y_n)$, on the other hand, m_2 would be negative, z^* would be below z^0 and the market would be too small. In this case, the marginal entrant would <u>improve</u> the distribution of an incumbent's potential neighbors.

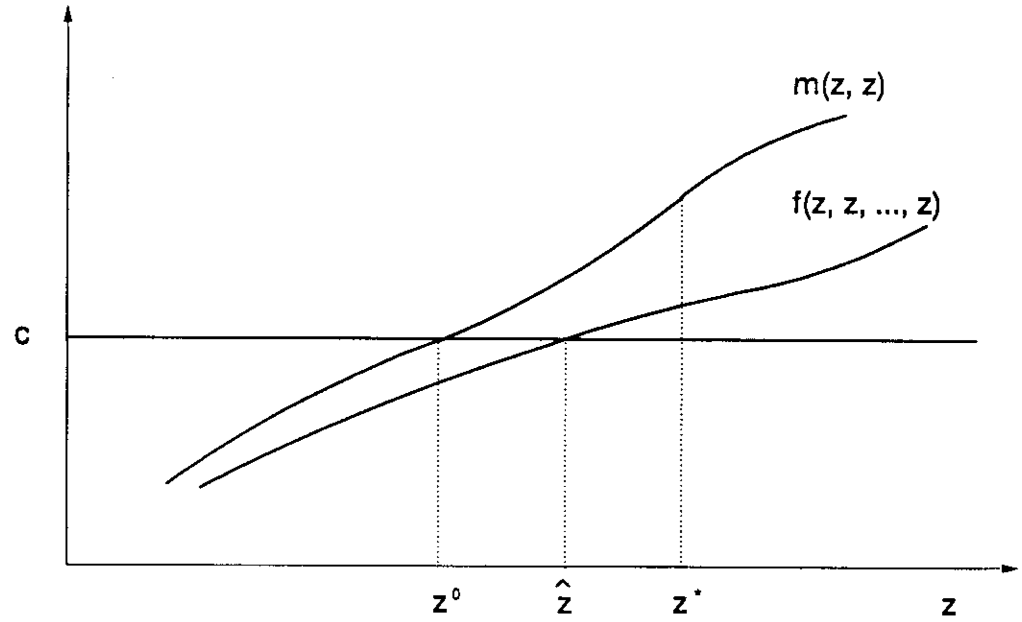

Figure 1: Uncoordinated Equilibrium (z^0), Competitive Equilibrium ($\hat{z}$), and Second-Best Optimum (z^*).

3. Competitive Equilibrium.

In this section I assume that firms can internalize the externalities and form teams of size $n+1$. If the firm hires $n+1$ agents of type $x_1, \ldots, x_{n+1}$, its output will be

$$\sum_{i=1}^{n+1} f(x_i, x_1, \ldots, x_{i-1}, x_{i+1}, \ldots, x_{n+1}) \equiv F(x_1, \ldots, x_{n+1}) .$$

Any permutation of the x's leaves the value of F unchanged; it is a symmetric function.

Assume that a worker of type x is paid a wage of $w(x)$. This assumes away all the informational and coordination problems of the previous section. Except for the presence of the fixed cost c, this situation is much like the one that

Kremer (1991) recently studied,[12] and I will describe it only briefly. Firms maximize profits by choosing types of workers to hire:

$$\max_{x_1,\ldots,x_{n+1}} \left\{ F(x_1,\ldots,x_{n+1}) - \sum_i w(x_i) \right\}.$$

The first order conditions for $x_1, \ldots x_{n+1}$ to be optimal are

$$F_i = w'(x_i) \qquad i = 1,\ldots,n+1 .$$

Now assume that $f_{ij} > 0$, which in turn implies that $F_{ij} > 0$.[13] Because of this, firms will hire workers of the same type.[14] Intuitively this is because the higher quality worker will command a higher value in a firm with other high quality workers. This means that

$$w'(x) = F_i(x,x,\ldots,x) , \quad \text{all } x .$$

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[12] Becker (1980) also studies the same issues in the context of the marriage market.

[13] This assumption may fail in some contexts, perhaps most notably in any process involving imitative learning as opposed to interactive learning. One would expect that laggards will have more to gain by being paired with smart people, than do bright people. Summers and Wolfe found this to be so in their study of student achievement: "... high achievers are relatively unaffected by variations in the percentage of top achievers. But, for the low achievers, the intellectual composition associated with other characteristics of the student body has a direct impact on learning." (1977, p. 647). This suggests that $f_{ij} < 0$ may be more appropriate in such contexts, and Jovanovic and Rob (1989) pursue this specification further.

[14] This result is in Becker (1980). It is more accurate to say that teams will be homogeneous. A firm can comprise several teams whose activities are independent, with no spillovers between teams.

This is the first condition characterizing an equilibrium in which firms hire workers of the same type. The second equilibrium condition ensures that firms make zero profits, so that the wage equals output per worker:

$$w(x) = \frac{1}{n+1} F(x, x, \ldots, x) .$$

This wage function is consistent with the first order condition because the symmetry of F means that $F_i(x, x, \ldots, x) = \frac{1}{n+1}\frac{dF}{dx}$. In other words, a competitive equilibrium <u>exists</u>. Let $\hat{z}$ be the marginal participant in competitive equilibrium. He must just cover the entry cost c which, since $F(x, \ldots, x) = (n+1)f(x, \ldots, x)$, means that

$$f(\hat{z}, \hat{z}, \ldots, \hat{z}) = c .$$

Since $m(z, z)$ and $f(z, z, \ldots, z)$ are both increasing in z (see Figure 1) and since $m(z, z) > f(z, z, \ldots, z)$, we have the following result:

<u>Theorem</u>. Competitive equilibrium market size is smaller than in an uncoordinated equilibrium. That is, $z^0 < \hat{z}$.

An immediate <u>corollary</u> is that the competitive equilibrium is <u>not</u> a Pareto improvement over the uncoordinated equilibrium. In the competitive equilibrium, agents whose x is in the interval $(z^0, \hat{z})$ are not participating, and are collecting a net payoff of zero which is strictly less than their payoff in the uncoordinated equilibrium.[15] Indeed, because $m(x, z^0)$ is continuous in x and because $m(\hat{z}, \hat{z}) > c$, as Figure 1 shows, even some competitive market participants are better of in an uncoordinated equilibrium.

4. The Size of the Welfare Loss.

Now let us get a rough idea of how big the welfare loss is under reasonable assumptions on f and G. So far I haven't been too specific about x, so let us now assume that it stands for the physical and human capital that a person has. In Lucas's (1988, 1990) framework, a doubling of physical and human capital will raise income per head by a factor of $1 + \gamma$, where γ measures the externality associated with human capital per head.[16] With this in mind, let

$$f(x, y_1, \ldots, y_n) = Axy_1^{\frac{\gamma}{n}} \ldots y_n^{\frac{\gamma}{n}} .$$

The assumed symmetry in the y_i is analytically convenient but violates the fact that some neighbors will be more important than others. The work of Scherer (1984), Jaffee (1986), and Bartelsman et al (1991) strongly suggests this. But it will, I think, be clear below that allowing the exponents of the y_i in f to differ would make little difference to the welfare calculations because in the

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[15] This is because $m(z^0, z^0) = c$, and because $m(\cdot)$ is strictly increasing in its first argument.

[16] Setting $u = 1$ in equation (11) of Lucas (1988) yields the following expression for output:

$$Ak^{\beta}h^{1-\beta}Nh_a^{\gamma},$$

where N is labor, and k and h are physical and human capital per head, and where in equilibrium $h = h_a$. I think of x as standing in for (k, h), and of $(y_1, \ldots, y_n)$ as proxying for h_a. Thus doubling each person's endowment in my model should raise aggregate output by a factor of $2^{1+\gamma}$.

first case the percentage welfare losses do not depend on n at all, while in the second they do not depend on n very much (see Figure 4). Still, this conclusion might not hold for other functional forms, and so the importance of heterogeneity of neighbors' contributions must for now remain an open question.

Assume that x is Pareto distributed:

$$G(x) = 1 - \left(\frac{x}{\beta}\right)^{-\alpha} \quad \text{for} \quad x \geq \beta > 0, \text{ and } \alpha > 0 \ .$$

To ensure that the upcoming integrals all exist, assume that $\alpha > 1 + \gamma$. The estimates that we shall come up with will meet this constraint, although just barely. Then calculations following from eq. (A.1) of the appendix imply that

$$m(x,z) = A\left(\frac{\alpha}{\alpha - \gamma/n}\right)^{n} xz^{\gamma} \ ,$$

so that setting $m(z, z) = c$ gives us

$$z^{0} = \left[\left(\frac{\alpha - \gamma/n}{\alpha}\right)^{n} \frac{c}{A}\right]^{\frac{1}{1+\gamma}} \ .$$

To get z^{*}, the planner chooses z to maximize net output:

$$Q(z) \equiv \beta^{\alpha}\left[\frac{A\alpha}{\alpha - 1}\left(\frac{\alpha}{\alpha - \gamma/n}\right)^{n} z^{1+\gamma-\alpha} - cz^{-\alpha}\right].$$

The first order condition for a maximum is

$$\frac{(1 + \gamma - \alpha)A\alpha}{\alpha - 1}\left(\frac{\alpha}{\alpha - \gamma/n}\right)^{n} z^{\gamma-\alpha} + \alpha c z^{-(1+\alpha)} = 0.$$

This equation has a unique solution for z:

$$z^{*} = \left[\left(\frac{\alpha - \gamma/n}{\alpha}\right)^{n} \frac{c}{A}\left(\frac{\alpha - 1}{\alpha - 1 - \gamma}\right)\right]^{\frac{1}{1+\gamma}} = \left(\frac{\alpha - 1}{\alpha - 1 - \gamma}\right)^{\frac{1}{1+\gamma}} z^{0} > z^{0}.$$

At z^*, the second order condition holds, assuring us that this is indeed the maximum. If $\gamma = 0$, both z^* and z^0 equal c/A, as they should. Substituting for z^0 and z^* into Q(z), we find that[17]

$$Q(z^{0}) = \frac{\beta^{\alpha} A^{\frac{\alpha}{1+\gamma}} c^{\frac{1+\gamma-\alpha}{1+\gamma}}}{\alpha - 1} \left(\frac{\alpha - \gamma/n}{\alpha}\right)^{-\frac{\alpha n}{1+\gamma}},$$

and that

[17] The derivations of the Q's are reported in the Appendix.

$$Q(z^*) = (1+\gamma)\left(\frac{\alpha - (1+\gamma)}{\alpha - 1}\right)^{\frac{\alpha}{1+\gamma}-1} Q(z^0) \; .$$

Hence the percentage gain in welfare at z^* relative to z^0 is

$$\frac{Q(z^*)}{Q(z^0)} = (1+\gamma)\left(\frac{\alpha - (1+\gamma)}{\alpha - 1}\right)^{\frac{\alpha}{1+\gamma}-1} ,$$

which depends on α and γ alone. As one would expect, this expression increases with γ and decreases with α -- the latter measures how tight the distribution of x is. The scope of spillovers, n, has no effect on the welfare gain.

We also want to know the welfare loss relative to the competitive equilibrium. The marginal agent's income is $f(\hat{z}, \ldots, \hat{z}) = A\hat{z}^{1+\gamma} = c$, from which we find that

$$\hat{z} = \left(\frac{c}{A}\right)^{\frac{1}{1+\gamma}} ,$$

(which is <u>between</u> z^0 and z^*), and net output is

$$Q(\hat{z}) \equiv \int_{z}^{\infty} [f(x,x,\ldots,x) - c]\,dG(x) = \frac{(1+\gamma)\beta^{\alpha} A^{\frac{\alpha}{1+\gamma}} c^{\left(\frac{1+\gamma-\alpha}{1+\gamma}\right)}}{\alpha - (1+\gamma)} ,$$

so that

$$\frac{Q(\hat{z})}{Q(z^0)} = \frac{(\alpha - 1)(1 + \gamma)}{\alpha - (1 + \gamma)} \left(\frac{\alpha - \gamma/n}{\alpha}\right)^{\frac{\alpha n}{1+\gamma}},$$

which depends on α, γ, <u>and</u> on n. The dependence on n, however, is weak:

$$\left(\frac{\alpha - \gamma/n}{\alpha}\right)^{\frac{\alpha n}{1+\gamma}} \Bigg|_{n=1} = \frac{\alpha - \gamma}{\alpha},$$

while taking the log and applying L' Hôpital's rule yields

$$\lim_{n\to\infty} \left(\frac{\alpha - \gamma/n}{\alpha}\right)^{\frac{\alpha n}{1+\gamma}} = e^{-\frac{\alpha\gamma}{1+\gamma}}.$$

The difference between these two expression is negligible when evaluated at the empirically relevant values of α and γ. Thus I shall report $Q(\hat{z})/Q(z^0)$ both at $n = 1$ and at $n = \infty$, and it will make little difference which expression is used, as the Figure 4 below will show.

We now need values for α and γ. First, γ is probably between .15 and .40. The latter is Lucas's estimate; he gets it by ascribing <u>all</u> the correlation between the Solow residual and schooling to the γ. This was a time series estimate for the U.S. Since the schooling time series is correlated with other shifters of the U.S. production function such as the level of knowledge in the rest of the world, the value of .40 is probably a loose upper bound.[18] The lower bound is based on the work of Bartelsman et al (1991) who control for factors that may cause an upward bias to the estimate of γ and who come up with a set of estimates that uniformly exceed .15.

I estimate α from the U.S. personal distribution of income from all sources in 1988. The data are taken from the census, and they include only those people who earned at least the minimum wage; people with incomes lower than that are likely to be part-timers -- an option that does not exist in the model.[19] The way that I estimate α is as follows: As n gets large, income differs from x by a multiple that is the same for everyone,[20] and so incomes too are Pareto distributed: $P_I \equiv P(\text{income} \geq I) = I_0^{\alpha} I^{-\alpha}$ for some constant $I_0 > 0$. Hence I will assume that n is large and use the least squares regression $\log P_I = \text{Constant} - \alpha \log I$ to estimate α. The result is

$$\log P_I = \underset{(2.5)}{13.4} - \underset{(.25)}{1.45} \log I, \qquad R^2 = .89 ,$$

the expressions in parentheses being standard errors.

The data and the regression line are displayed in Figure 2. The fit is good and I shall use the point estimate $\alpha = 1.45$.

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[18] Although even larger estimates are reported in Table 2 of Wolff and Nadiri (1991), they do not differ significantly from .40.

[19] The data are taken from Table 12 of U.S. Department of Commerce (1989), and they displayed in Figure 2. Incomes less than $5,000 were ignored because they fell short of the then legal minimum wage of $6,968 per year.

[20] Because the term $y_1^{\gamma/n}, \ldots, y_n^{\gamma/n}$ converges almost surely to a constant.

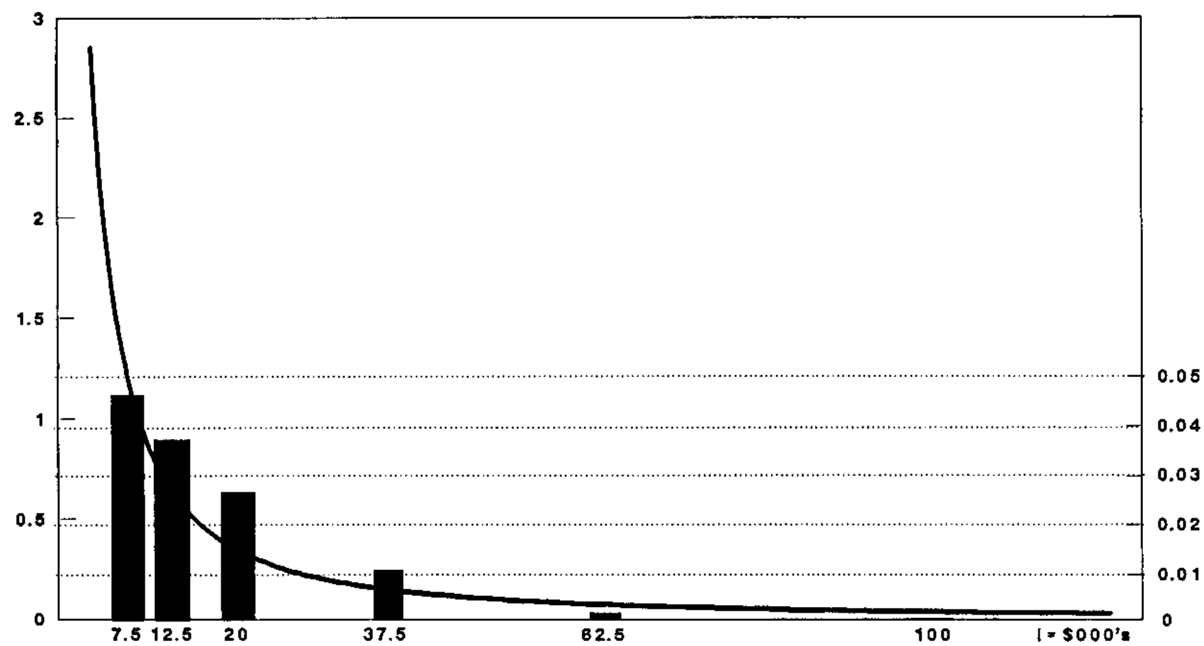

Figure 2: Actual and Fitted Income Distributions

We can now estimate $Q(z^*)/Q(z^0)$ and $Q(\hat{z})/Q(z^0)$, the latter evaluated first at $n = 1$, and then at $n = \infty$. These losses are plotted in Figures 3 and 4 for various values of γ. Taking the relevant range for γ to be .15 - .40, the losses relative to second best range from 3.5% to 30% of GNP, while losses relative to the competitive equilibrium range from 43% to a staggering 900% of GNP! This says that if $\gamma = .40$, an economy in which people are perfectly assigned to one another will have a GNP nine times that of an economy in which assignments are random.

To put these estimates into perspective, let us retrace how we arrived at them. The symbol x stands for a person's physical and human resources, and some portion of x is observable: a person's education, their assets, parts of their employment history, all are usually on record. Social arrangements can and

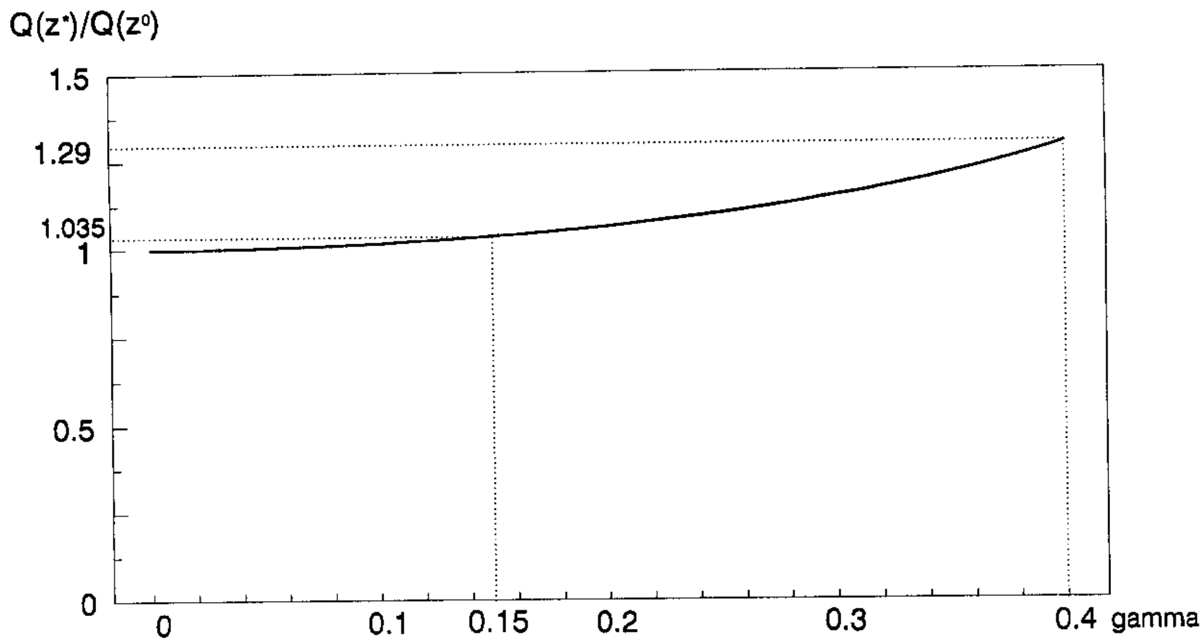

Figure 3: Welfare Losses Relative to Second Best

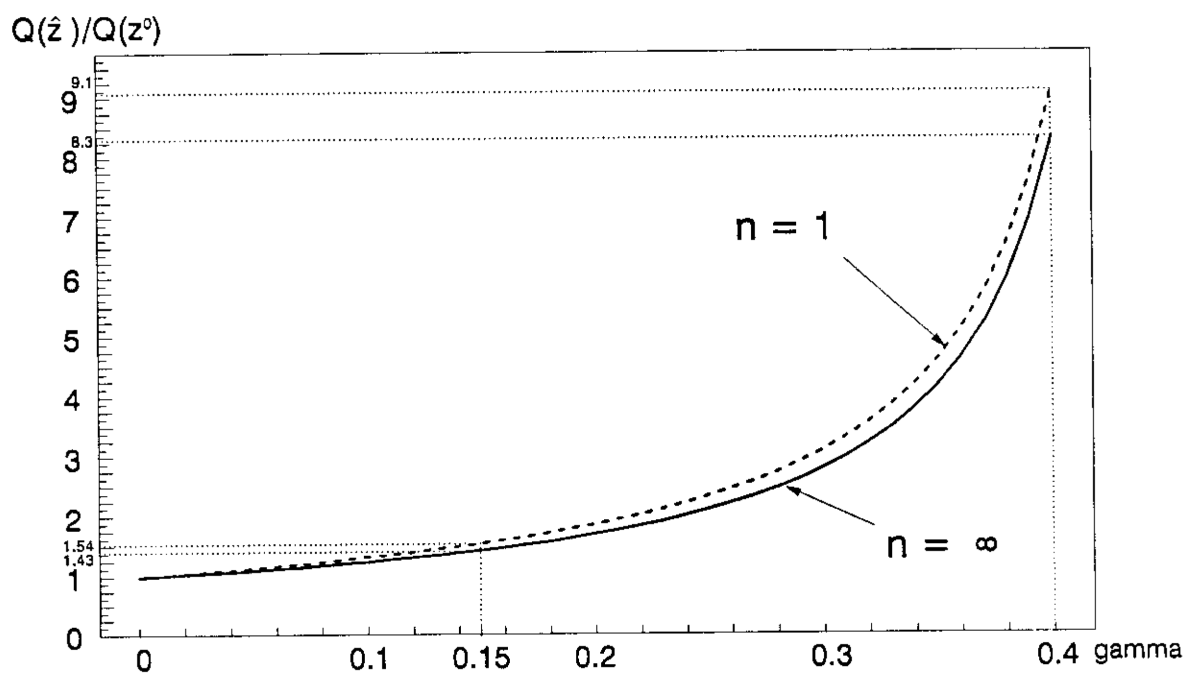

Figure 4: Welfare Losses Relative to the Competitive Equilibrium

do use this information to assign the person to an activity where he is expected to be the most productive. We expect that the unobserved portion of x therefore varies less than implied by my estimate of α. And since the welfare measures are decreasing in α, as is the variance of x, this biases my measures upward.

But most of x is probably not observed. Consider first the human capital component. Detailed labor histories like the NLS and the PSID samples contain more data on a person than his prospective employer will, and yet this information is a relatively poor predictor of earnings, accounting for at most about 30% of the earnings variation. Second, x may stand for the quality of an entrepreneurial opportunity that only its finder knows and would not want to reveal for fear of losing the rents that go with it.

The economy is surely somewhere in between the two polar extremes that I have described in sections two and three. The situation is complicated by the passage of time which brings in information about ones own x or about the x's of one's current and potential future partners.[21] An indirect way to measure the contribution that learning has towards improving the quality of assignments is to compare how much of earnings variation <u>observables</u> can explain at different ages. If x has an unobservable component, but if that component is initially unknown, it can not influence assignments, and hence can not influence initial

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[21] In Jovanovic (1979, 1982) I analyzed two such learning processes, essentially two versions of the "multi-armed bandit" problem in statistics. In this situation the quality of a person's match does tend to improve with time, but a person does not, even asymptotically, end up in his optimal match. In Jovanovic and Moffitt (1990) we estimated the productive value of the "job-match" type of information at between 6 and 9 percent of GNP. We arrived at that number by valuing, at equilibrium prices, the output that would be lost if agents could not act on their match-specific information by exercising their option to change jobs. The number measured what society would lose if it, in effect, threw away its match-specific information. Comparing that number to the numbers reported here for $Q(\hat{z})/Q(z^0)$ suggests that the information that people accumulate in the market is but a small fraction of the universe of productively useful information.

earnings through that channel. But it can affect earnings later on, once it is revealed through market experience. Hence observables should do a better job of explaining earnings variation at young ages than later on in life. This is indeed the case, but the difference is quite small. Mincer and Jovanovic (1981, Table 1.6) estimated wage functions for the NLS young men and the NLS older men separately and they found that while R^2 was higher for the sample of young men, it exceeded the older men's R^2 by only 2 to 3 percent. So, the effect is there but it is small.[22]

A further complication is that the unexplained variation in personal incomes is not solely due to imperfections in coordination; for instance there is transitory variation in income, and there is variation due to geographical cost of living differentials, both of which increase the cross-sectional dispersion of incomes. Flinn (1986) estimates the transitory component to be

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[22] The relevant comparison is between the regressions that do not include job-tenure (an endogenous variable); in both cases the dependent variable is the logarithm of the wage, and t-statistics are in parantheses.

	Constant	Education	Experience	Experience^2	R^2
Young Men	-.03	.08	.07	-.002	.194
		(17.9)	(7.4)	(3.2)	
Older Men	.67	.07	.01	.0002	.175
		(10.4)	(.14)	(.22)	

Source: Table 1.6 of Mincer and Jovanovic (1981).

A further puzzle is the lower coefficient of schooling for the older men inspite of the presumed superiority of their assignments. The two polar log-earnings functions are

$$\log f = \log A + \log x + \frac{\gamma}{n}\sum_{i=1}^{n} \log y_i \qquad \text{(random assignment)}$$

and

$$\log f = \log A + (1+\gamma) \log x \qquad \text{(perfect assignment)} .$$

Hence an observable component of x (such as education) should have a higher coefficient in the second case.

small, but in any case these considerations also serve to bias upward my welfare estimates.

5. Conclusion.

This paper has estimated the production gains to perfect coordination over an uncoordinated outcome, and found them to be potentially quite large. The estimates are rough and are meant to provide an idea of order of magnitude only. Since management practice and hence the degree of coordination changes over time and differs over countries, we have here a potentially important explanation for the growth in the Solow residual over time, or for its great cross-country variability.

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Appendix:

Derivation of some of the formulas in section 4: The starting point is to note that for any $p \in (0, \alpha)$

$$E(y^p \mid y \geq z) = \alpha z^{\alpha} \int_z^{\infty} y^{p-(1+\alpha)} dy = \frac{\alpha z^p}{\alpha - p} . \qquad (A.1)$$

This is because x and the y_i are independent and all have the same distribution. Substitution from (A.1) and from the expression for z yields the expressions in the text. I now report the derivation of the Q's, because of their relative complexity.

$$Q(z^0) = \beta^{\alpha}\left[\frac{\alpha}{\alpha-1}\left(\frac{\alpha}{\alpha-\gamma/n}\right)^{n}\left(\frac{\alpha-\gamma/n}{\alpha}\right)^{\frac{n(1+\gamma-\alpha)}{1+\gamma}} Ac^{\frac{1+\gamma-\alpha}{1+\gamma}} A^{\frac{\alpha-1+\gamma}{1+\gamma}} - c\left(\frac{\alpha-\gamma/n}{\alpha}\right)^{-n\alpha} c^{\frac{-\alpha}{1+\gamma}} A^{\frac{\alpha}{1+\gamma}}\right]$$

$$= \frac{\beta^{\alpha} c^{\frac{1+\gamma-\alpha}{1+\gamma}}}{\alpha-1} A^{\frac{\alpha}{1+\gamma}} \left(\frac{\alpha-\gamma/n}{\alpha}\right)^{\frac{-\alpha n}{1+\gamma}} .$$

$$Q(\hat{z}) = \int_z^{\infty} [Ax^{1+\gamma} - c]\beta^{\alpha}\alpha x^{-(1+\alpha)} dx = \alpha\beta^{\alpha}\left\{A\int_z^{\infty} x^{\gamma-\alpha} dx - c\int_z^{\infty} x^{-(1+\alpha)} dx\right\}$$

$$= \beta^{\alpha}\left\{A\frac{x^{1+\gamma-\alpha}}{1+\gamma-\alpha}\Big|_z^{\infty} + c\frac{x^{-\alpha}}{\alpha}\Big|_z^{\infty}\right\}$$

$$= \alpha\beta^{\alpha}\left\{A\frac{z^{1+\gamma-\alpha}}{\alpha-(1+\gamma)} - \frac{cz^{-\alpha}}{\alpha}\right\} = \alpha\beta^{\alpha}\left\{\frac{c^{\frac{1+\gamma-\alpha}{1+\gamma}} A^{\frac{\alpha}{1+\alpha}}}{\alpha-(1+\gamma)} - \frac{c^{\frac{1+\gamma-\alpha}{1+\gamma}} A^{\frac{\alpha}{1+\gamma}}}{\alpha}\right\}$$

$$= \alpha\beta^{\alpha} c^{\frac{1+\gamma-\alpha}{1+\gamma}} A^{\frac{\alpha}{1+\gamma}}\left\{\frac{1}{\alpha-(1+\gamma)} - \frac{1}{\alpha}\right\} = \beta^{\alpha} c^{\frac{1+\gamma-\alpha}{1+\gamma}} A^{\frac{\alpha}{1+\alpha}} \frac{1+\gamma}{\alpha-(1+\gamma)} .$$

$$Q(z^*) = \beta^\alpha \left[\frac{\alpha}{\alpha - 1} \left(\frac{\alpha}{\alpha - \gamma/n}\right)^n \left(\frac{\alpha - \gamma/n}{\alpha}\right)^{\frac{n(1+\gamma-\alpha)}{1+\gamma}} \left(\frac{\alpha - 1}{\alpha - 1 - \gamma}\right)^{\frac{1+\gamma-\alpha}{1+\gamma}} AA^{\frac{\alpha-(1+\gamma)}{1+\gamma}} c^{\frac{1+\gamma-\alpha}{1+\gamma}} \right.$$

$$\left. - \left(\frac{\alpha - \gamma/n}{\alpha}\right)^{-\frac{\alpha n}{1+\gamma}} \left(\frac{\alpha - 1}{\alpha - 1 - \gamma}\right)^{-\frac{\alpha}{1+\gamma}} cc^{-\frac{\alpha}{1+\gamma}} A^{\frac{\alpha}{1+\gamma}} \right]$$

$$= \beta^\alpha c^{\frac{1+\gamma-\alpha}{1+\gamma}} A^{\frac{\alpha}{1+\gamma}} \left(\frac{\alpha - \gamma/n}{\alpha}\right)^{-\frac{\alpha n}{1+\gamma}} \left(\frac{\alpha - 1}{\alpha - 1 - \gamma}\right)^{-\frac{\alpha}{1+\gamma}} \left[\frac{\alpha}{\alpha - 1} \left(\frac{\alpha - 1}{\alpha - 1 - \gamma}\right) - 1\right].$$

But

$$\frac{\alpha}{\alpha - 1} \left(\frac{\alpha - 1}{\alpha - 1 - \gamma}\right) - 1 = \frac{\alpha}{\alpha - (1+\gamma)} - 1 = \frac{1 + \gamma}{\alpha - (1+\gamma)} .$$

Therefore

$$Q(z^*) = \frac{1 + \gamma}{\alpha - (1+\gamma)} \left(\frac{\alpha - 1}{\alpha - (1+\gamma)}\right)^{-\frac{\alpha}{1+\gamma}} \beta^\alpha c^{\frac{1+\gamma-\alpha}{1+\gamma}} A^{\frac{\alpha}{1+\gamma}} \left(\frac{\alpha - \gamma/n}{\alpha}\right)^{-\frac{\alpha n}{1+\gamma}} .$$

$$Q(z^*) = \frac{(1+\gamma)(\alpha-1)}{\alpha - (1+\gamma)} \left(\frac{\alpha - (1+\gamma)}{\alpha - 1}\right)^{\frac{\alpha}{1+\gamma}} Q(z^0) ,$$

which, when rearranged, becomes the expression given in the text.