The Economics of Human Cloning[1]

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To be, or not to be, that is the question.

Hamlet, III, 1.

1 Introduction

According to many experts, human cloning is around the corner.[1] Indeed, there are reports that it has already taken place.[2] Overcoming the technical obstacles is a matter of a few years, and ethical considerations, which were unable to halt the spreading of in vitro fecundation, egg trading, or frozen embryos, are again unlikely to prevail. As pointed out by the National Bioethics Advisory Commission (NBAC) (1997), "The history of infertility treatment demonstrates that where there is a sizable and well financed demand for a novel service, there will be professionals willing to provide it". Banning by national governments will not be very effective either, as there will always be states willing to liberalize such practices, if anything because it will serve as a source of foreign exchange and tax revenues.[3] Therefore, we expect that in the near future cloning will be customarily used for therapeutic purposes, as well as added to the set of techniques already available to people who have difficulty having children. These are the two applications that are most commonly envisioned and that nourish the current debate. Several lawyers argue that it should be allowed, as an application of the principle of reproductive freedom.[4]

[1] See Green (1999) for a description of the technique and an assessment of the pace of future research, as well as a discussion of some ethical problems. A more detailed analysis can be found the the National Bioethics Advisory Commission's report (1997).

[2] "South Korean Scientists Say They Cloned a Human Cell", *The New York Times,* December 17, 1998

[3] As an example, Valiant Venture Ltd, based in the Bahamas, claims to offer people the opportunity to clone themselves for the sum of 200,000 $. Interested readers can consult their home page at http://www.clonaid.com. The author of this paper cannot be held responsible for any events that would occur should a reader decide to purchase any service from that corporation.

[4] See Robertson (1998). As for Orentlicher (1999), cloning actually enhances the stability of families, as compared to existing means of assisted reproduction which introduce

In this paper, however, we consider the more speculative consequences of cloning for *economic* reasons. Many people would argue that this hypothesis belongs to science-fiction and that human selfishness could not go as far. But we want to point out that there will be strong economic incentives to clone people of exceptional value in the labor market. Clearly, it is of great economic value to clone a top entrepreneur (such as Bill Gates), a top surgeon, or a top scientist such as Einstein.[5] [6]

The extent to which the market will internalize this economic value depends on how much of the return to the clone's genes can be appropriated by the agents who invested in creating the clone—mostly, the clone's original model.[7] We argue (in section 2) that the fraction that can be appropriated is likely to be small, but positive. If the clone's expected income is very large, this may be enough for cloning to be a profitable operation. A market for clones will then start operating, and we show (section 3) that only the most talented people will be cloned, while women (i.e., everybody in our a-sexual model) at the bottom of the ability distribution will specialize as physical mothers of the clones, thus getting a higher income than if working in the production sector.[8] Because of this effect and because it raises the proportion

genes alien to the family into its offsprings.

[5] An interesting aspect is that there will be greater incentives to clone workers whose skills are not replicable by *other means*. For example, the books written by a top economist are replicable at low cost, and this will reduce the value of cloning the economist; the skills of a surgeon are much harder to replicate. In other words, there is some substitutability between *biotechnology* and *information technology.* In fact, cloning is just another new information technology applied to life. The DNA is a sequence of bits and cloning is no different from copying a computer programme.

[6] It is typically envisioned that if cloning is ever permitted for reproductive reasons, it will be limited to infertile couples (See Robertson (1999)). However, I do not see how this is compatible with equal rights; furthermore enforcing such a distinction might not be obvious.

[7] It should be pointed out that the existence of the clone need not impose any externality on the model. Typically, an intermediary would offer the model to buy some of his or her DNA, perhaps with an exclusivity clause. The model does not have to ever see his clone.

[8] The idea that people would not accept to serve as surrogate mothers was already dismissed in Watson's (1971) visionary article, which was written some years after a frog had been successfully cloned, but prior to the first successful in vitro fecundation. He writes:

"There already are such widespread divergences regarding the sacredness of the act of of top ability workers, cloning affects the distribution of income.

This is studied in section 4, which analyzes the consequences of cloning for the long-run distribution of abilities. This depends both on fertility and on how an offspring's ability is related to that of its parents. We consider various hypotheses. First, we assume that the ability distribution among natural children is the same as among parents[9]. In such a case, whenever cloning arises, it drives the economy to a situation where all agents have the highest ability level, and where cloning has eventually disappeared. We then consider a weaker assumption where the distribution of genes, rather than abilities, is invariant through sexual reproduction. In such a case one can only prove that cloning eliminates ability-reducing genes in the long run. We also consider the implications of mutation and of a negative income dependence in fertility rates. In this latter case, cloning eventually produces a two-class society, with top ability agents who are typically cloned, and bottom ability agents who typically act as surrogate mothers.

The empirical relevance of this paper's analysis clearly depends on the extent to which earnings ability is genetically transmitted. The issue is far from settled empirically.[10] Surely, a fair share of the variance of earnings is acquired. For example, Ashenfelter and Krueger (1994), using a sample of identical twins, find returns to education as high as 12-16 %. This does not mean, however, that genes do not matter. Some evidence suggests that ability test scores are more correlated between twins raised apart than between non-twins reared together (See Bouchard and McGue (1981)). Furthermore, heritable physical traits such as weight and size affect earnings (See Blanchflower and Sargent (1994)).

More fundamentally, an individual supplies a vector of characteristics to

human reproduction that the boring meaninglessness of the lives of many women would be sufficient cause for their willingness to participate in such experimentation (...)".

[9] This will be the case if fertility is uncorrelated with income and if a child's ability is randomly chosen between his mother's and his father's ability.

[10] Cf. the heated "Bell curve" debate in the 1990s. (Herrnstein and Murray, 1995; Devlin et al. 1997; Cawley et al. 1996; Ashenfelter and Rouse (1998)).

the labor market, some of them are acquired (such as having a good network of connections or knowing where to locate valuable information), others at least partly innate (such as having a good memory or reacting quickly). His salary depends on the vector of implicit prices of each characteristic, which depends on technology[11] and may thus vary with time. Consequently, the extent to which earnings potential is heritable is likely to be affected by technical change. It is plausible that in recent decades acquired characteristics have become more important. However, nothing precludes that this trend be reversed in the future.[12] In any case, this paper is exploratory and does not advocate any view on that unresolved issue. Obviously, if none of ability is heritable, then cloning has no specific economic implication relative to normal reproduction.

While, since 1997, lawyers have dealt seriously with the complex legal issues associated with human cloning, to my knowledge there is hardly any paper in economics that deal with that topic. One exception is Posner and Posner (1998). Their approach is quite different from that of the present paper. They are concerned with the extent to which sexual reproduction may be driven out by cloning. They consider several mechanisms. One is that if people care a lot about their children's ability, in any couple the most able partner would prefer to clone him or herself rather than engage in sexual reproduction with the other partner. Another is that to the extent that infertile people will use cloning to produce as many offsprings as fertile ones, and that fertile couple sometimes produce infertile offsprings, infertiles genes will drive out fertile ones in the long run. In contrast, in this paper, I assume a taste for sexual reproduction and consider the role of cloning as a financial investment. As in Posner and Posner it does affect the long term genetic characteristics of population but in a quite different way.

[11] For example, if glasses did not exist, being myopic would surely be severely penalized in the labor market.

[12] Conceivably, new information technology such as the internet could reduce the value of knowing how to locate information. See Hassler and Rodriguez Mora (2000) for a model where the relative importance of intelligence vs. social background depends on the economic environment.

2 A market for clones?

If a clone were treated as a product, it could be patented. Those who put up the resources needed to produce the clone could then reap all the returns to the clone's genes by forcing 'it' in the highest return occupation and expropriating all its labor income. In this case, the market would internalize the 'social benefits' of cloning and produce a large number of copies of Bill Gates and of various top physicians and lawyers. Moral hazard could mitigate these effects, but the producers could still get considerable returns on their investment by imposing an adequate incentive contract.

However, clones are human beings, and are likely to be granted the same civil rights as other individuals (although this is not totally obvious)[13]. No slavery can be imposed on them, and they don't have to abide by the terms of a contract they have not signed. If they can appropriate all the returns to their genes, the private economic incentives for cloning will be non existent. People cannot be patented.

This brings the following question: in a free, democratic society, what sort of devices could investors use to appropriate part of the labor income of an individual they have produced? Let us suggest the following appropriability mechanisms.

The simplest one is a *negative bequest.* The clone could be legally adopted by its model and the model would borrow money that would implicitly be backed by the clone's future earnings. Such negative bequests are illegal in most western countries, but not in Japan, for example. Negative bequests come close to full appropriability of the clone's income.

Another possibility is *information retention.* A cloning firm could buy some DNA from a top ability individual and produce a clone thousands of kilometers away. The original individual would not know anything about his/her clone. When the clone has reached his legal majority, the firm would

[13] The National Bioethics Advisory Commission (1997) advocates that "any children born as a result of this technique should be treated as having the same rights and moral status as any other human being".

sell him information about the model: genealogy, career, etc. This information would also be verifiable by any potential employer. Upon being contacted by the firm, the individual would learn that he or she is the clone of a top ability worker. He is then willing to pay a substantial amount of money to know whether he is the clone of a violinist or a surgeon. Thus, by withholding information about the model's specific talent, the firm is able to appropriate part of the clone's labor income.

An extreme form of information retention is *genome ownership.* There is now a debate about whether genetic code could be patented. If this turns out to be legal, the firm could simply own property rights over the model's genome and its clones could have the option to buy it, so as to use it in order to improve their health and labor market prospects. In the former case, their motivation for buying their genome is unrelated to their earnings ability; nevertheless, their willingness to pay for it is likely to be greater, the greater their earnings. Hence the incentive to clone top performers remains. By making clones, the firm would then simply generate customers for a given genome.

Finally, one could potentially extract rents from clones via *education.* The returns to higher education are higher for top ability people. But there aren't that many top schools, so that competition among those schools is low. As a result they are able to extract rents from their students in the form of tuition fees and gifts. They expect to get greater rents from more able students. Hence, a consortium of top schools could invest in the cloning of top individuals, knowing that a fair fraction of these clones will get educated at a top school.

Clearly these mechanisms are far weaker than slavery, and will generate an equilibrium level of cloning much lower than if clones were granted fewer rights than original human beings. However, it is not unreasonable to speculate that if the income prospects of the individual are large enough, there will be enough incentives for cloning him or her even at such low appropriability levels.

Contractibility problems associated with the surrogate mother, on the other hand, are lighter, despite the fact that she would legally be the mother of the child. The firm could make sure the clone develops properly by having her sign a contract specifying her diet during pregnancy, etc. It could monitor the clones' health during pregnancy, and so forth. One should note, however, that once the clone exists there will be a situation of bilateral monopoly between the surrogate mother and the firm. For example, the surrogate mother could extract rents from the firm by refusing to send the child to a good school unless she is bribed. Each aspect of the clone's life that has not been contracted upon ex-ante will be exposed to hold-up by the surrogate mother, which reduces appropriability. Such problems already arise regarding existing techniques of assisted reproduction.[14]

To conclude this section, let us point out that, just like cloning need not be banned in all countries, some countries may develop a legal system where clones have fewer rights. Clearly, different cultures have different views about say, the rights of women or children, so they might also treat clones differently. If this is so, appropriability may be high in a subset of countries. Even if these countries are small, by attracting foreign direct investment in cloning they may contribute to a high level of cloning worldwide.

3 Cloning in an overlapping generations model

In this section, we set up the model's main assumption and derive its predictions about the equilibrium level of cloning. The complete solution is postponed to the next section.

There are overlapping generations of "agents", each living two periods.

[14] See Posner (1989). According to Chester (1997), Dr. Joseph Schulman, the director of the Genetics and IVF Institute, advocated in June 1997 that such problems should be solved by writing a "complete" contract between the parties involved. Chester claims that there is a legal vacuum surrounding these issues and that such contracts should be regulated for equity reasons, given the unequal bargaining power of parents, surrogates, and fertility clinics. He also reports a New Jersey case of a conflict between a (genetic) surrogate mother and the inseminator's household, where the surrogacy contract was invalidated but custody was granted to the latter.

Only the young work. The young differ by their ability a, which is interpreted as productivity per unit of time and distributed over $[\underline{a},\bar{a}]$. This assumption implies that productivity types are perfect substitutes. The utility of a member of generation t is given by

$$U_t = \ln c_{yt} + \beta \ln c_{ot+1} + \gamma \ln n_{yt} \tag{1}$$

,where $c_{yt}, c_{ot+1,}$ and n_{yt} are consumption when young, consumption when old, and number of children, respectively. Thus people derive utility from having children. By children we refer to sexually produced ones. Thus, we rule out any 'narcissist' or 'megalomaniac' motive for cloning; people are not made happy by the existence of a copy of themselves.[15]

Young agents have a fixed time endowment, which we normalize to one. We assume that there is a time cost b per child of raising children. People can raise children for themselves or clones of other people, acting as a surrogate mother. In the latter case they are paid p_t. p_t is the equilibrium price of a clone, or equivalently the rental rate of a womb. All wombs are equivalent, so that p_t does not depend on the surrogate's characteristics. There is no cost of cloning other than the time of surrogate mothers.[16] Consequently, in order to clone oneself, an individual just has to transfer p_t to the surrogate. Many of the results below are based on the assumption that surrogacy cannot be

[15] We are conscious that this assumption runs counter to sociobiological arguments that relate altruism to the 'coefficient of kinship', i.e. to the number of genes shared between the altruistic individual and the individual who benefits from altruism. See Dawkins (1990), Wilson (1974) for an exposition of these arguments based on natural selection.

What is unclear, at this stage, is whether this argument can be extended to claim that a taste for artificially producing clones will evolve as an outcome of natural selection. Taking as granted that altruism has evolved as the outcome of 'kin (or 'group') selection', it is also true that diploid reproduction has evolved and that only very simple organisms are reproduced in a non sexual way. Many Darwinists would argue that sexual reproduction increases genetic diversity, thus making the group or species more adaptable to changes in its environment. Groups where cloning is too important might disappear. In the long run, cloning prohibition might appear, just like incest prohibition has evolved.

[16] Clearly, one could be more general and assume the existence of a competitive biotech industry which would take care of the technical costs of cloning. Intuitively, this would not change our results. Imperfect competition in the cloning industry would raise interesting issues, but they are beyond the scope of our paper and may not be specific to cloning.

avoided. This could be challenged since scientists have already given birth to goats in artificial rubber wombs.[17] In the appendix, we briefly discuss how the condition for cloning to arise would be changed if only capital, rather than human time, were needed to produce clones.

Clones have exactly the same ability as their model. When old, a cloned individual can appropriate a fraction φ of his clones' income. φ is determined by the considerations developed in the previous section. Note also that people do not want to extract income from their own children.

Therefore, the budget constraint is

$$c_{yt} + \frac{c_{ot+1}}{1+r_{t+1}} \leq aw_t(1 - b(n_t + \nu_t)) + \frac{1}{1+r_{t+1}}\varphi y_{t+1}(a)\mu_t - \mu_t p_t + \nu_t p_t, \tag{2}$$

where w_t is the wage rate per unit of productivity at date t, r_{t+1} the interest rate between t and $t+1$, ν_t the number of clones produced by the agent at t, and μ_t the number of clones of itself bought by the agent at t. The term $\frac{1}{1+r_{t+1}}\varphi y_{t+1}(a)\mu_t$ is the present discounted income generated by the agent's clones. $y_{t+1}(a)$ is the labor income of an agent with ability a at date $t+1$. If such agents produce $n_{t+1}(a)$ own children and $\nu_{t+1}(a)$ clones of others, then $y_{t+1}(a) = aw_{t+1}(1 - b(n_{t+1}(a) + \nu_{t+1}(a)))$.

Agents maximize (1) with respect to $c_{yt}, c_{ot+1}, \nu_t, n_t$, and μ_t subject to their budget constraint (2) and their time constraint

$$b(n_t + \nu_t) \leq 1 \tag{3}$$

Interest rates and wages are determined by the production function and the dynamics of capital accumulation. We shall follow the standard assumptions made in overlapping generations models. The young acquire next period's capital stock, the production function has constant returns to scale, and perfect competition ensures that factors are paid their marginal product. These properties will be used later in the paper. For the time being

[17] See Christie and Von Radowitz (1997); Hadfield (1992), and Kuwabara (1992).

we derive the consumption and fertility decisions in partial equilibrium, i.e. taking wages and interest rates as exogenous.[18]

3.1 The demand for cloning

We start by deriving the demand for cloning, i.e. the first-order conditions with respect to μ. Given that it does not enter utility nor the time constraint, agents will set μ so as to maximize the RHS of (2). Since it is linear in μ and consumption cannot be infinite, it must be nonincreasing in μ for all a, implying

$$\frac{1}{1+r_{t+1}}\varphi y_{t+1}(a) \leq p_t, \forall a$$

We realistically assume that $y_{t+1}(a)$ is increasing with a, which will turn out to be true in equilibrium. It follows that in equilibrium the demand price for cloning is determined by the most able type's willingness to pay, i.e.

$$p_t = \frac{1}{1+r_{t+1}}\varphi y_{t+1}(\bar{a}). \tag{4}$$

Therefore, only the highest ability agents will be cloned. Because, for a given p, there is no limit to the replication of a given individual, and because the gains from cloning oneself are increasing with ability (since one knows for sure that the clone will have the same ability as the original), the most able agents bid up the price of cloning until less able people are driven out the market. This phenomenon would be mitigated if there were no perfect substitutability across ability types, in which case the amount of cloning in each type would be determined so as to equate incomes across clones.

Thus the demand for cloning is infinitely elastic. In particular, it does not depend on the density of people at the highest ability level. One could even assume that a large fraction of the population does not want to clone itself. It is enough that *some* individuals at the highest ability level are willing to

[18] The following discussion is also correct in general equilibrium provided the production function is linear, $F(K, L) = rK + wL$.

do so to boost the price to the level determined by (4).[19] The number of clones that will be produced does not depend on demand, but on supply. A reduction in the number of high-ability workers willing to be cloned will simply be offset by an increase in the number of times each of them is cloned.

Note that cloning is an investment, an alternative to investing in physical capital. Indeed, (4) is an arbitrage condition between these two types of investments. However, we shall assume that in a representative agent economy it would not be as profitable as physical capital, in a way to be made more precise below (see eq. (H0)).

3.2 The supply of clones

We now turn to the supply of clones, i.e. the determination of ν. Again, the RHS of (2) is linear in ν. Consequently, if $p_t < bw_t a$, the agent will choose $v = 0$; if $p_t > bw_t a$, then the agent will choose the highest possible value of ν, i.e. $\nu = 1/b - n$.

Therefore, there exists a threshold level of ability, determined by

$$a_t^* = \frac{p_t}{w_t b}, \tag{5}$$

below which agents will entirely specialize in the production of clones, and above which they will entirely specialize in production.[20] Low ability agents have a comparative advantage in producing clones. This threshold increases with the price of clones and falls with the opportunity cost of producing children, equal to the product of the wage and the time cost of child raising.

How many clones will low ability people produce? We can straightfor-

[19] According to a 1997 poll, about 6 % of the people are willing to clone themselves. See "Clone the clowns", *The Economist,* March 1 1997.

[20] Here "specialization" refers to the time left to market activities (cloning and production), once the time used to raise one's own children has been subtracted.

wardly solve for their optimization problem and get the following solution:

$$
\begin{aligned}
c_{yt} &= \frac{\nu_t p_t}{1+\beta} = \frac{p_t}{b(1+\beta+\gamma)} \\
c_{ot} &= \frac{\beta(1+r_{t+1})p_t}{b(1+\beta+\gamma)} \\
n_{yt} &= \frac{\gamma}{b(1+\beta+\gamma)} = n \\
\nu_t &= \frac{1+\beta}{b(1+\beta+\gamma)} = \nu.
\end{aligned}
$$

Therefore, these agents will produce the same number of children and clones, regardless of their ability. Their income is entirely due to cloning and does not depend on ability.

The total supply of cloning is therefore given by

$$N_t \nu F_t(a_t^*), \tag{6}$$

where N_t is the size of the young cohort at t and $F_t(.)$ the cumulative distribution of skills in that cohort.

We can also compute consumption and fertility for non-cloned agents who do not produce clones ($a > a_t^*$). It is easy to see that, for these agents, maximization of (1) subject to (2) and (3) yields

$$
\begin{aligned}
c_{yt} &= \frac{w_t a(1-bn_{yt})}{1+\beta} = \frac{w_t a}{1+\beta+\gamma} \\
c_{ot} &= \frac{\beta(1+r_{t+1})w_t a}{1+\beta+\gamma} \\
n_{yt} &= \frac{\gamma}{b(1+\beta+\gamma)} = n \\
\nu_t &= 0.
\end{aligned}
$$

These equations also hold for non-clones of the highest ability type $a = \bar{a}$; competition among them eliminates any potential rents they could get from cloning themselves, so that their budget constraint is unaffected by cloning. Things are slightly different, however, for clones. They must transfer an amount $\varphi w_t \bar{a}(1 - bn_{yt})$ to their model. One can then check that the solution is

$$\begin{aligned}
c_{yt} &= \frac{w_t \bar{a}(1 - bn_{yt})(1-\varphi)}{1+\beta} = \frac{w_t \bar{a}(1-\varphi)}{1+\beta+\gamma} \\
c_{ot} &= \frac{\beta(1+r_{t+1}) w_t \bar{a}(1-\varphi)}{1+\beta+\gamma} \\
n_{yt} &= \frac{\gamma}{b(1+\beta+\gamma)} = n \\
\nu_t &= 0.
\end{aligned}$$

Clones are poorer than equivalent, sexually produced, workers because they "owe" money to their blueprint. This results in lower consumption but in the same number of children.[21] Thus, a convenient feature of the model is that all ability types will produce the same constant number n of sexually produced children. This is somehow a desirable property of the model, since otherwise the initial distribution of abilities could not be in a long-run steady state.

Finally, the labor income of top ability agents is

$$y_{t+1}(\bar{a}) = w_{t+1}\bar{a}(1 - bn) = \frac{w_{t+1}\bar{a}(1+\beta)}{1+\beta+\gamma}. \tag{7}$$

3.3 Equilibrium cloning

There will be a positive amount of cloning if the demand price, as determined by (4), yields a value of the threshold in (5) which is higher than the minimum ability level $\underline{a}$. This is equivalent to

$$\underline{a} < \frac{\varphi y_{t+1}(\bar{a})}{(1+r_{t+1})\, bw_t} = a_t^* \tag{8}$$

In steady state, this condition is equivalent to

$$b\frac{\underline{a}}{\bar{a}} < \frac{1+g}{1+r}\frac{1+\beta}{1+\beta+\gamma}\varphi, \tag{9}$$

[21] This is because utility is logarithmic and because the cost of children is in terms of time rather than labor income.

where g is the growth rate of labor-augmenting total factor productivity. This condition is more likely to hold,

- the lower the cost of producing children, b.
- the higher the appropriability of clone income φ
- the higher the growth rate g
- the lower the equilibrium rate of return r
- The lower the relative taste for children, as measured by $\gamma/(1+\beta+\gamma)$
- the lower the ratio between the lowest and highest ability level $\frac{a}{\bar{a}}$.

The first two properties simply capture the costs and benefits of cloning. As cloning is an investment, which transforms present costs into future revenues, a higher cost of capital reduces it, while faster growth increases its future returns. The effect of the taste for children comes from the fact that only labor income is appropriable from clones; therefore, a greater propensity to make children will reduce their labor income and therefore the return from cloning.[22] Finally, the most interesting property is the last one, which tells us that cloning is more likely to arise in more inegalitarian societies. Cloning is more likely to arise, the lower the opportunity cost of time of those who produce clones relative to the income of those who get cloned, i.e. the greater inequality.

If (8) holds, then the total number of clones is simply obtained by substituting (4) and (5) into (6). One gets

$$\nu N_t F_t(\frac{1}{1+r_{t+1}}\frac{\psi\bar{a}w_{t+1}}{bw_t}),$$

where $\psi = \varphi(1-bn) = \varphi(1+\beta)/(1+\beta+\gamma)$ is introduced to save on notation, and refers to the income extracted from clones relative to their

[22] This effect would not appear if one could appropriate a fraction of total *earnings capacity* aw_{t+1} instead of labor income $aw_{t+1}(1-bn)$.

maximum earnings potential. These people all have the highest ability level $\bar{a}$.

Thus, society will organize itself in three classes: a *reproductive* class at the bottom of the distribution of ability; a *productive class* at intermediate levels; and a *replicated* class at the very top of the ability distribution. As in an ant society, there is a relationship between reproduction technology and economic status.[23]

3.4 Cloning vs. Sex

A relevant question is: why don't we observe, even in the absence of cloning, a market for sexually produced human beings? The answer is that this is not ruled out a priori, but the incentives for such a market to arise are weaker than in the case of cloning. There are two types of reasons for that. First, given the large randomness associated with the offspring's characteristics, the appropriability mechanisms described in the previous section are likely to be much weaker. Second, the fact that reproducers are selected at the bottom of the ability distribution inevitably reduces the average ability of the offspring, and thus the income that can be extracted from it.

Assume that on average the ability of the offspring is equal to the mean ability of its parents. Then if the most able agent "buys" a child from a supplier of ability a, the expected present discounted value of income associated with that operation is

$$\frac{\psi w_{t+1}}{1+r_{t+1}}\frac{\bar{a}+a}{2}.$$

In equilibrium this must be equal to the price $q_t(a)$ of a child from a reproducer with ability a :

$$q_t(a) = \frac{\psi w_{t+1}}{1+r_{t+1}}\frac{\bar{a}+a}{2}.$$

[23] Similarity to an ant society could be increased if there was no specific taste for sexual reproduction, in which case cloning could eventually displace sexual reproduction for the most able type, as Posner and Posner (1998) argue can happen.

This equation determines the demand price for an offspring sexually produced with a mate of ability a. As in the cloning case, competition will ensure that only the highest ability agents are willing to pay for such a descendent. Contrary to the cloning case, the price of an offspring now depends on the ability of the reproducer, since it affects the offspring's quality.

If both cloning and sexual reproduction can be purchased, then cloning will always dominate as $q_t(a) < p_t$.

Suppose now that cloning is not available. What we can prove is that given factor prices, a market for sexual reproduction is less likely to be viable than a market for cloning. To see this, first note that as above, people will specialize in reproduction–i.e., mating with high ability agents– iff $q_t(a) > w_t ab$. In equilibrium, people will again specialize in reproduction if and only if their ability does not exceed a threshold given by[24]

$$a_t^+ = \frac{\psi w_{t+1}\bar{a}}{2b(1+r_{t+1})w_t - \psi w_{t+1}}. \tag{10}$$

In equilibrium, one must always have $a_t^+ \leq a_t^*$. For this not to hold, one would need that $\psi w_{t+1} > b(1+r_{t+1})w_t$. But this is impossible, since according to (4) one would then have $a_t^* > \bar{a}$, implying that all people specialize in reproduction and that output is zero.

The fact that $a_t^+ \leq a_t^*$ implies that there exists a range of values of $\underline{a}$ where a market for cloning arises but not a market for sexual reproduction. If φ is small, a_t^+ is about half the value of a_t^*. These results would be strongly reinforced if only that part of the clones' income which is above some fixed "subsistence" level were appropriable.[25] In such a case, the rents that could be appropriated from an average ability agent could be zero or orders of magnitude smaller than those appropriable from a top ability person. The

[24] The other possibility cannot be an equilibrium outcome. For high ability people to specialize in reproduction one would need that $q_t(a)$ is steeper than $w_t ab$, i.e. $\varphi w_{t+1}/2(1+r_{t+1}) > w_t b$. But then, it is easy to see that everybody would specialize in reproduction, since a zero-ability worker would surely do so.

[25] i.e., one would appropriate $\varphi \max\{w_{t+1}a - \sigma_{t+1}, 0\}$, out of an offspring of ability a, where σ_{t+1} is the subsistence level.

prospects for a market for cloning would accordingly be much greater than those for a market for sexual reproduction.

To summarize, the comparative advantage of low ability agents in reproduction creates an adverse selection problem which drives down the quality of sexually produced offsprings, thus reducing the viability of the market. This problem is solved in the cloning case because the offspring is then identical to its high-quality blueprint.

However, that is not the end of the story. In the current state of technology, two top-ability parents could produce an offspring using IVF and implant it into the womb of a low ability surrogate mother[26]. If the offspring were of top ability, this would not be different from cloning from an economic point of view. The present model can then be viewed as an analysis of the economic consequences of advanced reproductive techniques rather than cloning per se. However, there are again some reasons to believe that this is less likely to arise than cloning. First, some appropriability techniques such as genome ownership are less feasible than in the case of cloning since the offspring's genome will be unique and not identical to either parent's. Second, each parent will ex-post compete with the other in order to extract rents from the offspring, which may again reduce appropriability. Third, two top ability parents may not produce a top ability offspring, as ability results from a set of unique combinations of genes that will be broken in the course of sexual reproduction.

4 Implications for the evolution of income distribution

We now discuss the implications of the model for the evolution of income distribution. To do so, we have to close it by deriving the dynamics of capital accumulation and of the hereditary transmission of ability.

[26] This is called "gestational surrogacy", as opposed to "genetic surrogacy".

4.1 Employment, capital, and factor prices

As in the Diamond (1965) model, the aggregate capital stock at $t+1$ must be equal to the stock of wealth accumulated by the young at t. This stock is equal to

$$\frac{\beta \nu_t p_t}{1+\beta},$$

for reproductive agents such that $a < a_t^*$;

$$\frac{\beta w_t a(1-bn_{yt})}{1+\beta},$$

for productive agents such that $a_t^* < a < \bar{a}$;

$$M_t \frac{\beta w_t \bar{a}(1-bn)(1-\kappa_t \varphi)}{1+\beta} - CL_t,$$

for all the top ability agents, where M_t is the mass of such agents, κ_t the proportion of clones among them, and CL_t the aggregate amount they spend on cloning, which in equilibrium must be equal to $N_t F_t(a_t^*) p_t \nu$.

These equations show that, in part because it is a substitute for physical investment, cloning tends to reduce savings and capital accumulation. The reason is twofold. First, it is sustained by a transfer from clone to model, which takes place when the former is young and the latter old. As such it reduces capital accumulation, as do all such transfers in OLG models. This effect is captured by the $-\kappa_t \varphi$ term in the last formula. Second, The price of the clone which is transferred from replicated agents to reproducers does not result in a lower consumption for the model, as it is compensated in annuity terms by the rent it will extract from its clones in the future. But it does result in an increase in consumption for the reproducer, whose current period income is increased. This effect is captured by fact that the sum of the reproducers savings is equal to $\beta CL_t/(1+\beta)$, which is less than the associated reduction in the replicated class's savings CL_t.

Aggregating these formulae across all young agents, we get an equation for capital accumulation:

$$K_{t+1} = -N_t \frac{\nu}{1+\beta} p_t F_t(a_t^*) + \frac{\beta}{1+\beta} w_t L_t - \frac{\beta}{1+\beta} M_t \kappa_t \psi w_t \bar{a}. \qquad (11)$$

The first term is the reduction in savings due to the transfer from high to low ability agents in the current generation, while the last term is the contribution of the transfer of the current generation's clones to their old blueprint. The central term is the standard one that would prevail absent cloning. Under our logarithmic preferences, people would save a constant fraction of their wage income.

L_t is total employment in efficiency units, which is computed by summing labor supply across all agents, taking into account that those with ability lower than a_t^* produce clones rather than output. Consequently, one must have

$$L_t = N_t(1-bn) \int_{a_t^*}^{\bar{a}} a dF_t(a) + M_t(1-bn).$$

The evolution equation for the proportion of clones κ_t is determined by

$$M_{t+1}\kappa_{t+1} = \nu N_t F_t(a_t^*).$$

The LHS is the total number of clones in generation $t+1$, which must be equal to the cloning rate ν times the total number of cloners $N_t F_t(a_t^*)$ in generation t, i.e. to the RHS.

Factor prices are equal to marginal products. To close the model we assume a Cobb-Douglas production function with full depreciation of capital:

$$Y_t = AK_t^{\alpha} L_t^{1-\alpha}.$$

Note that to simplify we rule out technical progress ($g = 0$). This production function implies that

$$w_t = (1-\alpha) AK_t^{\alpha} L_t^{-\alpha} \qquad (12)$$

$$1 + r_t = \alpha A K_t^{\alpha-1} L_t^{1-\alpha}. \quad (13)$$

Furthermore, we shall assume that the following restriction holds:

$$n\frac{\alpha(1+\beta)}{\beta(1-\alpha)} > \frac{\psi}{b}. \quad \text{(H0)}$$

This assumption guarantees that in steady state a_t^* is strictly below $\bar{a}$.[27]It amounts to assuming that the return to capital is greater than the return to using one's time to clone oneself, i.e. that capital accumulation is superior to cloning as a technology to transfer value across time periods.[28]

4.2 Conservationist population dynamics

In order to complete the characterization of the model's dynamics, we must now derive the evolution of the distribution of abilities. We shall consider two alternative hypotheses.

The first possibility that we consider is that population dynamics obey a conservation law, in that the distribution of abilities across sexually produced offsprings is identical to the ability distribution of their parents. Given that each type produces the same number of offsprings, the distribution of genes will surely be the same in the next generation of naturally produced children. This does not imply, however, that the distribution of genotypes (in our case, ability), will be the same. This depends in a complex way on which genes determine ability, how they interact with each other, and what are the dominance relationships among their alleles. Given our ignorance on that

[27]If this is not the case, then a fraction of top-ability agents must produce clones, while the others produce output. This proportion is determined by the fact that in equilibrium they must be indifferent between these two activities.

[28]For an individual with ability a, $1/wa$ units of time generate 1 unit of income. During that time, the individual can produce $1/(bwa)$ clones. Each clone yields an income equal to ψwa next period. The gross return to that investment is therefore ψ/b. This has to be compared with $1+r$, the return to capital. One can check that in steady state it is equal to the LHS of (H0).

matter, the conservationist hypothesis is a benchmark worth considering.[29][30] In a subsection, however, we consider the (weaker) results that obtain if the conservation law applies to genes rather than abilities.

It is then very easy to characterize the evolution of the ability distribution. First of all, total (young) population evolves according to:

$$N_{t+1} = nN_t + \nu N_t F_t(a_t^*). \tag{14}$$

The first term in the RHS is the contribution of sexually produced offsprings, while the second term is the contribution of clones. The nN_t sexually produced children have the same distribution of abilities as their N_t parents. Therefore, the total density of agents with ability $a < \bar{a}$ evolves according to

$$N_{t+1} dF_{t+1}(a) = nN_t dF_t(a) \tag{15}$$

Finally, the mass of agents at the highest ability level $\bar{a}$ evolves according to

$$M_{t+1} = nM_t + \nu N_t F_t(a_t^*). \tag{16}$$

A comparison of equations (15) and (16) makes it clear that unless $F_t(a_t^*) = 0$, the mass of top ability agents will grow more rapidly than the rest of the population. In this case, the fraction of potential suppliers of cloning must go to zero, since top-ability workers do not supply cloning. Consequently,

PROPOSITION 1 - Cloning vanishes in the long run:

$$\lim_{t \to \infty} F_t(a_t^*) = 0.$$

[29] It is compatible with a variety of assumptions about intergenerational income mobility. For our purpose, we do not have to specify that process. See, however, Becker and Tomes, 1979, for a model of intergenerational mobility which explicitly takes into account genes, culture, and luck.

[30] Note that if such a conservation law holds for any distribution and any subset of the population, then it must be that two top-ability parents produce a top ability offspring. In this case cloning can be mimicked by implantation of a sexually produced embryo in a surrogate gestational mother.

This proposition tells us that if the conservationist hypothesis holds, cloning for economic reasons is a transitory phenomenon which gradually moves the economy to a situation where it has disappeared. There are two ways this can happen. Either the economy ends up entirely made of top-ability workers, and there are no potential suppliers of clones—that is, the market for cloning gradually shrinks to become negligible; or the economy reaches a situation where (8) does not hold, in which case cloning stops in finite time. The following proposition tells us which of these two cases prevail in steady state, depending on parameter values.

PROPOSITION 2 - If

$$\frac{n\alpha(1+\beta)}{\beta(1-\alpha)}\frac{\underline{a}}{\bar{a}} > \frac{\psi}{b}, \tag{H1}$$

then there exists a unique equilibrium path such that $a_t^* < \underline{a}$. The market for cloning is shut in all periods and the economy converges to the no-cloning steady state.

If (H1) does not hold then the trajectory is such that

(i) *Cloning arises at least every other period*: $\forall\ t\ \exists s \in \{t, t+1\}, a_s^* > \underline{a}$.

(ii) *The economy converges to a steady state where all agents have the highest ability level:*

$\lim M_t/N_t = 1$ *and* $\lim F_t(a) = 0, \forall a$.

PROOF - See Appendix.

Proposition 2 gives a condition for cloning to arise, equation (H1), which is stated in terms of the model's fundamental parameters, unlike the partial equilibrium condition (9). (H1) is equivalent to stating that $\underline{a}$ is greater that a^* in a no cloning steady state. The corresponding value of a^* in such a case is precisely equal to $\frac{\psi}{b}\bar{a}\frac{\beta(1-\alpha)}{n\alpha(1+\beta)}$.

Prop. 2 also derives the implications of cloning for the long-run distribution of ability. Basically, if (H1) holds, cloning never arises along the convergence path and the economy behaves as a standard Diamond OLG economy. If it does not hold, then cloning will arise almost always, but will vanish in the long run as the relative size of cloners converges to zero. The economy converges to a perfectly egalitarian society where all agents have the highest possible ability level. Note that reproduction is only sexual in the long run. The conservationist assumption plays an important role in ensuring that sexual reproduction among top-ability agents only yields top-ability offsprings. This long-run equilibrium could not be sustained if sexual reproduction introduced some noise in the distribution of offsprings' abilities. That is, under the conservationist hypothesis the ability distribution drifts under the pressure of transitory events without any tendency to return to the mean. Therefore, even a vanishing amount of cloning is enough to transform it permanently into a perfectly egalitarian distribution.

The determinants of (H1) are somewhat similar to those of (9). The novelties are the following. First, given ψ, a higher rate of time preference (a lower β) reduces the prospects for cloning, as it implies lower savings and a higher cost of capital. Second, an increased share of capital α increases interest rates relative to wages, again reducing the incentives for cloning. Finally, faster population growth also makes cloning more costly by reducing the capital/labor ratio, i.e. increasing the cost of capital.

Note that since cloning becomes negligible in the long run, the economy achieves the same capital/labor ratio and therefore the same wage rate per unit of ability as the economy without cloning. This is not true, however, of the transition to the steady state. When cloning is introduced, workers at the bottom of the ability distribution benefit by changing their specialization. Their income rises relative to others, whose welfare is unchanged. In the subsequent generation, all agent types lose relative to what they would have had absent cloning, because of the reduction in capital accumulation; again, with the exception of those who specialize in cloning. This is compensated by the fact that on average people have a greater ability, but a given ability type is worse-off.

4.2.1 A genetic counterpart

While the conservation law for the distribution of abilities is a convenient tool, it is more correct, as we argued above, to think of the distribution of *genes* to be invariant via sexual reproduction. It is then possible to extend proposition 2 to apply it to genes rather than ability levels. For shortness the result we prove is only concerned with the long run steady state of an economy where the market for cloning arises.

To express our model in terms of genetic fundamentals, we assume that the genetic code of any given individual is an n-uple $(g_1, ...g_N)$ where each $i = 1, ...N$ indexes the location of the gene and each gene is drawn from a given set G. We assume that the distribution of genes among sexually produced offsprings is the same as among parents. We denote the distribution of genes at date t by a measure μ_t over G. Ability is a function of one's genetic code, described by the following function:

$$a = h(g_1, ..., g_N)$$

Let $S(a) = \left\{g \in G \mid \forall (g_1, ...g_N) \in G^N, (\exists i \text{ s.t. } g_i = g \Longrightarrow h(g_1, ...g_N) < a)\right\}$. $S(a)$ is the set of genes such that if an individual has one of them, then his ability is strictly below a. Clearly $S(a) \subset S(a')$ for $a < a'$.

We make the following assumption, which is the counterpart of (H1) being violated:

$$\mu_0(S(\frac{\psi}{b}\bar{a}\frac{\beta(1-\alpha)}{n\alpha(1+\beta)})) > 0 \tag{H2}$$

This means that at the initial date $t = 0$ there is a strictly positive measure of genes that prevent ability from being above $\frac{\psi}{b}\bar{a}\frac{\beta(1-\alpha)}{n\alpha(1+\beta)}$, which, as we have seen, is the value of a^* that would prevail in an equilibrium steady state without cloning.

*Proposition 3 - Assume (*H0*) and (*H2*) hold. Then in any steady state* $\mu(S(\bar{a})) = 0$.

PROOF - Top ability people cannot have any gene in $S(\bar{a})$. Therefore, these genes are only transmitted via sexual reproduction. This is also true for any $S(a)$ with $a < \bar{a}$. For $\mu(S(\bar{a}))$ to be strictly positive in steady state, there must not be any cloning. Otherwise the genes of top ability people would increase in frequency from a generation to the next, which would reduce $\mu(S(\bar{a}))$. On the other hand, the conservation law of genes implies that

$$\frac{\mu_0(S(\frac{\psi}{b}\bar{a}\frac{\beta(1-\alpha)}{n\alpha(1+\beta)}))}{\mu_0(S(\bar{a}))} = \frac{\mu(S(\frac{\psi}{b}\bar{a}\frac{\beta(1-\alpha)}{n\alpha(1+\beta)}))}{\mu(S(\bar{a}))}.$$

i.ė., cloning affects the relative proportions between sexually transmitted and cloned genes, but not between two sexually transmitted genes.

Since (H2) holds, it must then be that $\mu(S(\frac{\psi}{b}\bar{a}\frac{\beta(1-\alpha)}{n\alpha(1+\beta)})) > 0$. But, since $\frac{\psi}{b}\bar{a}\frac{\beta(1-\alpha)}{n\alpha(1+\beta)}$ is the value of a^* that prevails absent cloning, this implies that there is a strictly positive mass of agents willing to specialize in surrogacy. This contradicts the fact that there must not be any cloning. Consequently, it must be that $\mu(S(\bar{a})) = 0$. Q.E.D.

Proposition 3 is clearly weaker than Proposition 2. It does not imply that all people are of top ability in the long run; nor is it true that cloning vanishes. It says that cloning will eventually eliminate genes that prevent ability to be at its maximum level. In particular, this applies to any gene which reduces ability when present in any individual. But, in the long run, other genes can be combined to produce ability levels below $\bar{a}$, which may even, in principle, be low enough to maintain the supply of cloning.

4.3 Mutation

The conservationist hypothesis generates some unit root in the distribution of income, so that even a small amount of cloning is enough to drive it to full equality in the long-run. In this section we relax the conservationist assumption by introducing mutation. Absent cloning, the ability distribution of mutants pins down the long-run distribution of ability. Therefore the initial ability distribution is no longer conserved.

We introduce mutation in the conservationist dynamics by assuming that with probability $1-q$ an offspring's ability is drawn from the previous distribution of abilities, while with probability q it is drawn from some exogenous distribution, which we will take as uniform. This is simple but tractable.

In this case, we can show that if (H1) is violated, there exists a balanced growth path with a constant, strictly positive proportion of the population being clones. On the other hand, if (H1) holds, the only steady states are non-cloning ones. Thus, mutation ensures that a positive fraction of the population is willing to provide clones by constantly dragging some mutants below the threshold ability level a_t^*. This prevents cloning from vanishing in the long run. This is summarized in the following proposition:

PROPOSITION 4 - Assume (H1) holds. Then the only balanced growth path has no cloning, i.e. is such that $a_t^* < \underline{a}$.

If (H1) is strictly violated, there exists a balanced growth path with a strictly positive fraction of clones. In that path the distribution of ability is the sum of a uniform distribution over $[\underline{a}, \bar{a}]$ *and a mass at the highest ability level* $\bar{a}$.

PROOF – See Appendix.

It would also be interesting to assume that sexual reproduction implies some regression to the mean (Becker and Tomes, 1986, find that regression to the mean is quick and only take about three generations). This would occur, for example, if the offspring's ability was an average of its two parent's ability. Provided mating is not entirely assortative (i.e. people only mate with people of the same ability), absent cloning the distribution would then converge toward a mass point at the initial mean ability level. In order to maintain diversity in the long run, one needs to assume a certain level of random mutation which offsets this tendency to regress to the mean. The distribution of abilities would then roughly follow some AR1 dynamics similar to the one just analyzed. Unfortunately, it is difficult to say more analytically because there is no explicit solution for the dynamics of income distribution.[31]

Note, however, that regression to the mean at the individual level is not incompatible with the conservationist hypothesis. For example, a child's ability may be equal to that of one of its parents, who would be randomly selected. If mating is not entirely assortative, then the income of the descendants of a given dynasty would regress to the mean in expectations, while the aggregate distribution of abilities would remain invariant absent cloning and with constant fertility across ability types.

4.4 Negative income dependence

In this section, we change the model's assumptions and assume that fertility and income are negatively related. From a methodological point of view, this is somewhat unsatisfactory, because it means that the initial distribution does not correspond to a long-run steady state. However, there is some empirical evidence that this is the case. For example, in the U.S. 1995 census, the birth rate was 91 per 1000 for women with a family income lower than 10,000 \$, 60 per 1000 for the 30,000-35000 \$ income range, and 53 per 1000 for a family income greater than 75,000 \$.[32]

With fertility correlated with ability, the conservation law collapses again. Absent cloning, the long-run distribution of income would collapse to a mass point at the most fertile group, i.e. the lowest ability level. When cloning is available, the top ability group is able to maintain its relative size through cloning. Indeed, the growth of the low ability group increases the 'supply' for clones proportionately, and even a single high-ability individual would be

[31] If instead we were considering that with probability $1-p$ the offspring's ability were the average of its parent's ability and the ability of a randomly drawn 'mate', then absent cloning the Fourier transform $\hat{F}_t$ of the ability distribution at t would evolve as

$$\hat{F}_{t+1}(\omega) = p\hat{U}(\omega) + (1-p)\left[\hat{F}_t(\frac{\omega}{2})\right]^2,$$

where $\hat{U}(\omega) = \frac{e^{i\omega\bar{a}} - e^{-i\omega\underline{a}}}{i\omega(\bar{a}-\underline{a})}$ is the uniform distribution's Fourier transform. Clearly, there is no tractable fixed point of that equation, except in the $p = 0$ case where it is of the form $e^{i\omega a_0}$, i.e. a mass point.

[32] See U.S. Census Bureau (1997), table A.

enough to produce that amount of clones. As a result, instead of converging to a fully egalitarian society with only the lowest ability level, the distribution of income converges to two mass points, one at the lowest ability level, the other at the highest one. Top ability people make fewer children than anybody else but their size is artificially maintained by cloning.

In order to modify the model to allow for negative income dependence in fertility rates, we simply assume that the weight of children in utility γ now depends on ability a, i.e. $\gamma = \gamma(a), \gamma' < 0$. This is less appealing than assuming a single nonlogarithmic utility function and getting negative income dependence as a result of the rich's higher opportunity cost of time. But it is enough to illustrate our results while keeping things simple.

Solving for people's utility maximization it is easy to see that agents of ability a will then have $n(a) = \gamma(a)/[b(1+\beta+\gamma(a))]$ 'natural' offsprings. The rest of the model is essentially unchanged, and we can prove the following

PROPOSITION 5 - Let $\bar{\psi} = \varphi(1 - bn(\bar{a})), \underline{\nu} = (1 - bn(\underline{a}))/b$. *Then there exists a unique equilibrium steady state such that*

(i) If

$$\frac{\alpha(1+\beta)}{\beta(1-\alpha)}\frac{\underline{a}}{\bar{a}} > \frac{\bar{\psi}}{bn(\underline{a})}, \tag{H3}$$

in steady state all agents have the lowest ability level $\underline{a}$ *and there is no cloning* ($\nu = 0$).

(ii) If

$$\frac{\alpha(1+\beta)}{\beta(1-\alpha)}\frac{\underline{a}}{\bar{a}} < \frac{\bar{\psi}}{bn(\underline{a})} < \frac{\alpha(1+\beta)}{\beta(1-\alpha)}\frac{\underline{a}}{\bar{a}}\frac{n(\underline{a}) + (n(\underline{a}) - n(\bar{a}))\frac{\varphi(1-\alpha)}{\alpha(1+\beta)}}{n(\underline{a}) - (n(\underline{a}) - n(\bar{a}))\varphi}, \tag{H4}$$

then the steady state distribution of ability has two masses at $a = \underline{a}$ *and* $a = \bar{a}$. *The cloning rate* ν *is between* 0 *and* $\underline{\nu}$. *The equilibrium proportion of top ability agents is*

$$m = \frac{\nu}{\nu + n(\underline{a}) - n(\bar{a})}.$$

Low ability agents are indifferent between working and producing clones, and split their time between both activities.

(iii) If

$$\frac{\bar{\psi}}{bn(\underline{a})} > \frac{\alpha(1+\beta)}{\beta(1-\alpha)} \frac{\underline{a}}{\bar{a}} \frac{n(\underline{a}) + (n(\underline{a}) - n(\bar{a}))\frac{\varphi(1-\alpha)}{\alpha(1+\beta)}}{n(\underline{a}) - (n(\underline{a}) - n(\bar{a}))\varphi}, \tag{H5}$$

then the steady state distribution of ability has two masses at $a = \underline{a}$ *and* $a = \bar{a}$*. The cloning rate* ν *is equal to* $\underline{\nu}$*. The equilibrium proportion of top ability agents is*

$$\frac{\underline{\nu}}{\underline{\nu} + n(\underline{a}) - n(\bar{a})}.$$

Low ability agents are entirely specialized in the production of clones.

Furthermore, in all cases population grows at rate $n(\underline{a})$*.*

PROOF - See Appendix.

To summarize this section, the long-run amount of cloning depends on the supply of physical mothers with an ability low enough to specialize in clone bearing. Under the conservationist hypothesis, cloning drives the ability distribution to the top, and eventually disappears because it has killed its own supply. On the other hand, mutation and negative income dependence boost the size of low ability groups, thus maintaining cloning in the long run. In the latter case, a two-class society emerges, with low ability people producing the clones of top ability ones.

5 Concluding remarks

In the model we have developed, there is an incentive to clone top ability individuals. Their surrogate mothers are recruited at the bottom of the distribution of income. The short-run effect is to reduce inequality; the long-run effect is to increase the proportion of top ability individuals, which may either increase or decrease inequality. If sexual reproduction preserves the distribution of ability, then only top ability individuals will exist in the long-run; they will only reproduce sexually but almost all of them will have clones in their ancestors. Under mutation or negative ability dependence of fertility rates, a mass of cloned top ability people coexists with a distribution of sexually produced, less able persons.

Thus we do not get the pattern of some anticipation novels such as Huxley's *Brave New World* where clones were found at the bottom of society. Rather, clones are made from an elite who sell their precious genes to the market. The explanation is simple: the value of cloning is highest for top ability people, and this maximum value determines the market price for clones. More fundamentally, there is no economic value in producing low-ability people via cloning rather than standard means.

We have refrained from engaging in the welfare analysis of cloning. It is impossible to do it without taking an ethical stand on the rights of clones. If they are treated as objects, efficiency require full appropriability of their income by their clonators. If they are treated as human beings, one has to overcome the difficulty of defining the utility of not existing.[33] Assuming this metaphysical problem is solved, one could then compute the effect of producing clones on social welfare, which would include the welfare of these clones. A trade-off would emerge between the quantity of clones produced and their happiness, as greater appropriability increases the quantity but also the transfer they make to their model.

The theory we have developed is neo-classical, in the sense that earnings are entirely determined by ability. This model is to be considered as a benchmark. Many assumptions could be challenged, and this could poten-

[33] This point is actually raised by Robertson's (1997) testimony before the NBAC, in the context of potential physical harm being done to the clone. See National Bioethics Advisory Committee (1997), ch. 4.

Interestingly, philosophers have tackled the issue, which they refer to as the non-identity problem. The question is: is giving life to an unhappy (in our model, poor) clone better than no life at all? Parfit (1984) actually uses an opportunity cost, utilitarian argument to argue that not, on the basis that a happier child could have been born instead.

tially lead to different results. For example, the appropriability parameter φ could vary in a way systematically correlated with ability, so that the cloned type would not be the highest ability one.[34]

The empirical relevance of this analysis also clearly depends on the extent to which ability is genetically transmitted. It will always be true that people with the 'best' genes will pay most for their clones. But the return from doing so are lower if it is not so clear that their clones will do as well as themselves. It would be interesting to extend the model by requiring that people acquire education. The bringing up of clones would then require not only low-skill physical mothers, but also high-skill educators.

We want to point out two important research directions. First, one could depart from our neo-classical assumptions and assume a segmented labor market where some workers are discriminated against. If discrimination is based on a genetically transmitted trait, such as ethnicity, then an incentive for cloning may arise even if genes were unrelated to productivity, and only members of the most favored ethnic group will be cloned even though they may not be more productive than members of less favored groups. Second, cloning may have important consequences for growth, because top ability people are instrumental in generating new products and processes. This is not captured by our model where labor is homogeneous and top ability people simply have a greater labor endowment than others.

[34] I am indebted to John Hassler for this point.

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Appendix

Proof of Proposition 2.

First of all, note that equation (4), which is equivalent to $p_t = \frac{1}{1+r_{t+1}}\psi w_{t+1}\bar{a}$, can be written as

$$p_t = \frac{\psi(1-\alpha)\bar{a}}{\alpha}k_{t+1}, \tag{17}$$

where $k_t = K_t/L_t$ is the capital/labor ratio.

Second, note that if cloning takes place at t, and/or has taken place at $t-1$, then equation (11) implies that

$$K_{t+1} < \frac{\beta}{1+\beta}w_t L_t$$

Dividing by L_{t+1}, this proves that if cloning takes place at t, one must have

$$k_{t+1} < \frac{\beta}{1+\beta}w_t \frac{L_t}{L_{t+1}},$$

or equivalently

$$\frac{L_{t+1}}{L_t} < \frac{\beta}{1+\beta}\frac{w_t}{p_t}\frac{\psi(1-\alpha)\bar{a}}{\alpha}.$$

Plugging in (5), this is equivalent to

$$\frac{L_{t+1}}{L_t} < \frac{\beta}{1+\beta}\frac{\psi(1-\alpha)\bar{a}}{b a_t^* \alpha} < \frac{\beta}{1+\beta}\frac{\psi(1-\alpha)\bar{a}}{b\alpha\underline{a}.}$$

The second inequality makes use of the fact that cloning takes place, i.e. that $\underline{a} < a_t^*$.

If (H1) holds, then this inequality implies

$$\frac{L_{t+1}}{L_t} < n - \varepsilon, \tag{18}$$

where ε is a strictly positive constant no greater than the gap between n and $\frac{\beta}{1+\beta}\frac{\psi(1-\alpha)\bar{a}}{b\alpha\underline{a}.}$.

Since cloning takes place at t, one must have $L_t < N_t(1-bn)E_t(a)$, where $E_t(a)$ is the average value of a at t. Next, note that because of cloning $N_{t+1} \geq nN_t$ and that $E_{t+1}(a) \geq E_t(a)$–i.e., population grows beyond the level corresponding to sexual reproduction, and average skill grows since clones all have the highest ability level while sexually reproduced offsprings have the same ability distribution as the previous generation. These two inequalities, along with (18), imply that $L_{t+1} < N_{t+1}(1-bn)E_{t+1}(a)$. Therefore, cloning must take place at $t+1$ as well, since not all labor resources are used in production. By induction, it follows that cloning takes place at all periods following t, so that (18) holds in all periods as well. Since total population grows by at least n, it follows that L_t/N_t converges to zero as t goes to infinity. For this to be the case, it must be that all agents eventually specialize in cloning, which cannot be an equilibrium since it yields a zero output level . This proves the first part of proposition 2.

Next, assume that (H1) is strictly violated. Consider a date t such that no cloning took place at $t-1$, implying $\kappa_t = 0$. Assume cloning does not take place at t. Then (11) implies that

$$K_{t+1} = \frac{\beta}{1+\beta} w_t L_t.$$

Using similar steps as above, we get that

$$\frac{L_{t+1}}{L_t} = \frac{\beta}{1+\beta}\frac{\psi(1-\alpha)\bar{a}}{ba_t^*\alpha} \geq \frac{\beta}{1+\beta}\frac{\psi(1-\alpha)\bar{a}}{b\alpha\underline{a}.} > n+\varepsilon. \tag{19}$$

The first inequality makes use of the assumption of no cloning at t, which is equivalent to $a_t^* \leq \underline{a}$. The second inequality uses the strict violation of (H1). Next, note that $L_t = N_t(1-bn)E_t(a)$ and that $N_{t+1} = nN_t$ and $E_{t+1}(a) = E_t(a)$. These three equality come from the absence of cloning at t. Finally, note that $L_{t+1} \leq N_{t+1}(1-bn)E_{t+1}(a) = nL_t$. This contradicts (19), implying that cloning must arise at t. This proves claim (i) in the second part of Proposition 2.

Let us now prove claim (ii). First, note that (14) and (16) imply that M_t/N_t is nondecreasing. Thus, if it does not converge to 1, it is bounded away from 1 throughout and converges to some maximum level $m < 1$. Assume that this is indeed the case. Then:

$$\frac{M_{t+1}}{N_{t+1}} = \frac{nM_t + \nu N_t F_t(a_t^*)}{nN_t + \nu N_t F_t(a_t^*)} < m < 1,$$

implying

$$F_t(a_t^*) < \frac{n\,(m - M_t/N_t)}{\nu(1-m)}.$$

As t grows, M_t/N_t becomes arbitrarily close to m, implying that $F_t(a_t^*)$ becomes arbitrarily small. Given that the total mass of agents below $\bar{a}$ converges from above to $1-m$, and that the distribution of these agents among ability types is the same as initially (because of the conservationist hypothesis), it must be that a_t^* also becomes arbitrarily close to $\underline{a}$ as t grows. Let $\varepsilon, \eta > 0$ and t_0 such that

$$[t > t_0 \Longrightarrow (a_t^* < \underline{a} + \varepsilon \wedge F_t(a_t^*) < \eta)]\,. \tag{20}$$

. This implies

$$\frac{\psi(1-\alpha)\bar{a}}{\alpha}\frac{k_{t+1}}{bw_t} < \underline{a} + \varepsilon \tag{21}$$

$$K_{t+1} > -N_t\frac{\nu}{1+\beta}p_t\eta + \frac{\beta}{1+\beta}w_tL_t - \frac{\beta}{1+\beta}\nu\eta N_{t-1}\psi w_t\bar{a}.$$

Dividing both sides by w_tL_{t+1} one gets

$$\frac{k_{t+1}}{w_t} > -\frac{N_t}{L_{t+1}}\frac{\nu}{1+\beta}\frac{p_t}{w_t}\eta + \frac{\beta}{1+\beta}\frac{L_t}{L_{t+1}} - \frac{\beta}{1+\beta}\nu\eta\frac{N_{t-1}}{L_{t+1}}\psi\bar{a} \tag{22}$$

Note that $N_t(1-bn)(1-\eta)E_t(a) < L_t < N_t(1-bn)E_t(a)$[35]; $nN_t < N_{t+1} < nN_t(1+\nu\eta)$;and $E_t(a) < E_{t+1}(a) < E_t(a) + \nu\eta\bar{a}/n$. [36]

[35] To get the first inequality, subtract the $F_t(a_t^*)$ proportion of clones producers from the maximum labor supply $N_t(1-bn)E_t(a)$ and note that an upper bound of their individual labor supply is $(1-bn)E_t(a)$, since their ability is below average.

[36] To get the second inequality, aggregate using (14)-(16) to get

$$E_{t+1}(a) = \frac{N_t}{N_{t+1}}\left[nE_t(a) + \nu\bar{a}F_t(a_t^*)\right],$$

and use the fact that $N_{t+1} > nN_t$ and $F_t(a_t^*) < \eta$.

These inequalities imply that

$$\begin{aligned}
\frac{N_t}{L_{t+1}} &< \frac{1}{n(1-bn)(1-\eta)E_t(a)} < \frac{1}{n(1-bn)(1-\eta)\underline{a}} = J_0 \\
\frac{L_t}{L_{t+1}} &> \left[n(1+\nu\eta)(1+\nu\eta\bar{a}/nE_t(a))\right]^{-1} > \left[n(1+\nu\eta)(1+\nu\eta\bar{a}/n\underline{a})\right]^{-1} \\
\frac{N_{t-1}}{L_{t+1}} &< \frac{1}{n^2(1-bn)(1-\eta)E_t(a)} < \frac{1}{n^2(1-bn)(1-\eta)\underline{a}} = J_1
\end{aligned}$$

Substituting these three inequalities into (22) and using (20) and (5), we get

$$\frac{k_{t+1}}{w_t} > -J_0\frac{\nu}{1+\beta}b(\underline{a}+\varepsilon)\eta + \frac{\beta}{n(1+\beta)}\frac{1}{(1+\nu\eta)(1+\nu\eta\bar{a}/n\underline{a})} - \frac{\beta}{1+\beta}\nu\eta J_1\psi\bar{a},$$

which can be rewritten as

$$\frac{k_{t+1}}{w_t} > \frac{\beta}{n(1+\beta)} + J_3(\eta),$$

where $J_3(\eta)$ becomes arbitrarily small when η goes to zero.

Similarly, (21) is equivalent to

$$\frac{k_{t+1}}{w_t} < \frac{\alpha b\underline{a}}{\psi(1-\alpha)\bar{a}} + J_2\varepsilon,$$

where J_2 is a constant. Hence we must have

$$\frac{\beta}{n(1+\beta)} < \frac{\alpha b\underline{a}}{\psi(1-\alpha)\bar{a}} + J_2\varepsilon - J_3(\eta).$$

On the other hand, strict violation of (H1) implies that there exists $\sigma > 0$ such that

$$\frac{\alpha b\underline{a}}{\psi(1-\alpha)\bar{a}} + \sigma < \frac{\beta}{n(1+\beta)}.$$

Picking up ε and such that $J_2\varepsilon - J_3(\eta) < \sigma$, one gets a contradiction.

Consequently, it must be the case that $m = 1$,i.e. $\lim M_t/N_t = 1$. The other property that $\lim F_t(a) = 0$ follows immediately, since $F_t(a) \leq 1 - M_t/N_t$.

Q.E.D.

Proof of proposition 4.

First note that if (H1) holds, then the no-cloning balanced growth path has a sequence of prices which preclude cloning.

Let us now try to construct a steady state equilibrium with cloning. Let $x = F(a^*)$ be the constant fraction of the population who provide clones. The evolution of the distribution of abilities is given by

$$M_{t+1} = (1-q)nM_t + \nu N_t F_t(a_t^*)$$

$$N_{t+1} = nN_t + \nu N_t F_t(a_t^*)$$

$$N_{t+1} dF_{t+1}(a) = (1-q)nN_t dF_t(a) + q\frac{nN_t}{\bar{a} - \underline{a}}$$

This implies that in steady state, the cumulative density dF is uniform and equal to

$$dF = \frac{qn}{(\bar{a} - \underline{a})(qn + \nu x)}.da \tag{23}$$

Consequently, x must satisfy

$$x = F(a^*) = \frac{qn(a^* - \underline{a})}{(\bar{a} - \underline{a})(qn + \nu x)}. \tag{24}$$

Finally we must have $M = N(1 - F(\bar{a}))$; i.e. the constant M/N ratio must be equal to

$$\frac{M}{N} = \frac{\nu x}{qn + \nu x} \tag{25}$$

Total labor supply in efficiency units may be computed as

$$\begin{aligned} L &= N \int_{a^*}^{\bar{a}} a.dF + \bar{a}M \\ \iff \frac{L}{N} &= \frac{qn}{2(qn + \nu x)} \frac{\bar{a}^2 - a^{*2}}{\bar{a} - \underline{a}} + \bar{a}\frac{\nu x}{qn + \nu x}. \end{aligned} \tag{26}$$

Drawing on (17), we see that the steady-state price of cloning is the related to the equilibrium capital/labor ratio k by

$$p = \frac{\psi \bar{a}(1-\alpha)}{\alpha} k. \tag{27}$$

Using (5), (27), and (12), we get that

$$a^* = \frac{\psi \bar{a}}{b\alpha A} k^{1-\alpha} \tag{28}$$

Finally, in steady state the capital accumulation equation (11) becomes

$$\begin{aligned} k &= \frac{-1}{n+\nu x}\left(\frac{N}{L}\right)\frac{\nu x}{1+\beta}\frac{\psi\bar{a}(1-\alpha)k}{\alpha} + \frac{\beta(1-\alpha)Ak^\alpha}{(1+\beta)(n+\nu x)} \\ & \quad - \frac{\beta}{1+\beta}\frac{\nu x\psi\bar{a}(1-\alpha)Ak^\alpha}{(n+\nu x)^2}\left(\frac{N}{L}\right). \end{aligned}$$

This is equivalent to, using (28)

$$\begin{aligned} & \frac{b\alpha}{\psi\bar{a}} a^* \left[1 + \frac{1}{n+\nu x}\frac{\nu x}{1+\beta}\frac{\psi\bar{a}(1-\alpha)}{\alpha}\frac{2(pn+\nu x)(\bar{a}-\underline{a})}{pn(\bar{a}^2 - a^{*2}) + 2\bar{a}(\bar{a}-\underline{a})\nu x}\right] \\ = & \frac{\beta(1-\alpha)}{(1+\beta)(n+\nu x)} - \frac{\beta}{1+\beta}\frac{\nu x\psi\bar{a}(1-\alpha)}{(n+\nu x)^2}\frac{2(pn+\nu x)(\bar{a}-\underline{a})}{pn(\bar{a}^2 - a^{*2}) + 2\bar{a}(\bar{a}-\underline{a})\nu x} \end{aligned} \tag{29}$$

Equations (24) and (29) jointly determine x and a^*. To solve the problem note that (24) defines a positive, monotonous relationship between these two variables, so that (29) can be treated as an equation in just one variable.

Assume that (H1) holds. Then the LHS of (29) is always greater than $\frac{b\alpha}{\psi\bar{a}}\underline{a}$, while the RHS is always smaller than $\frac{\beta(1-\alpha)}{(1+\beta)n}$. If (H1) holds, then $\frac{b\alpha}{\psi\bar{a}}\underline{a} > \frac{\beta(1-\alpha)}{(1+\beta)n}$, implying that (29) has no solution. It is therefore impossible to construct a steady state with a positive level of cloning, implying that the no cloning steady state is the only one.

Assume now that (H1) is strictly violated. At $a^* = \underline{a}$, one has $x = 0$, and violation of (H1) implies that the LHS of (29) is strictly smaller than the RHS. Consider now the point $a^* = \bar{a}$, corresponding to $x = (-pn + \sqrt{p^2n^2 + 4\nu pn})/2\nu$. At that point the LHS of (29) is greater than $b\alpha/\psi$, while the RHS is strictly smaller than $\frac{\beta(1-\alpha)}{(1+\beta)n}$. Given that (H0) holds, one has

$b\alpha/\psi > \frac{\beta(1-\alpha)}{(1+\beta)n}$, implying that the LHS is greater than the RHS. By continuity there exists $a^* \in]\underline{a}, \bar{a}[$ such that (29) and (24) simultaneously hold. (27),(26), (25), and (23) then allow to compute the other variables characterizing this steady state. This completes the proof of prop. 4.

Proof of proposition 5.

First, note that in any steady state the density of people of ability strictly between $\underline{a}$ and $\bar{a}$ must be zero, since the growth rate of these people is strictly below $n(\underline{a})$. Consequently, any steady state has only people of the two extreme types. Let m be the constant proportion of top ability people in such a steady state. Then the number of top ability people M_t evolves according to

$$M_{t+1} = M_t n(\bar{a}) + (N_t - M_t)\nu, \tag{30}$$

where N_t is total population and ν is the total number of clones produced by each low ability type. The number of low ability people evolves according to

$$N_{t+1} - M_{t+1} = (N_t - M_t)n(\underline{a}) \tag{31}$$

Since N and M grow at the same constant rate in steady state, this equation implies that this common rate must be $n(\underline{a})$. Dividing both sides of (30) by M_t we get that $n(\underline{a}) = n(\bar{a}) + (1/m - 1)\nu$, implying

$$m = \frac{\nu}{\nu + n(\underline{a}) - n(\bar{a})}. \tag{32}$$

Using again (4) and (5), we get that the critical value a^*, in steady state, is given by

$$a^* = \frac{\varphi\bar{a}(1 - bn(\bar{a}))}{b(1+r)},$$

where r is the steady state interest rate.

The capital accumulation equation (11) can be written as

$$\begin{aligned} K_{t+1} &= \frac{\beta}{1+\beta}w_t L_t - \frac{\beta}{1+\beta}\varphi(1 - bn(\bar{a}))\bar{a}w_t\nu N_{t-1}(1-m) && (33) \\ &\quad -N_t\frac{\nu}{1+\beta}(1-m)\frac{\varphi w_{t+1}\bar{a}(1 - bn(\bar{a}))}{1+r_{t+1}} && (34) \end{aligned}$$

The labor force is

$$L_t = N_t m\bar{a}(1 - bn(\bar{a})) + N_t(1 - m)\underline{a}(1 - bn(\underline{a}) - b\nu) \tag{35}$$

A steady state may be in one of three regimes:

Regime 1: $\nu = 0$. In this case, $m = 0$ and (33), along with the factor price equations, implies that the constant capital labor ratio k satisfies

$$n(\underline{a}) = \frac{\beta(1-\alpha)}{1+\beta} Ak^{\alpha-1}. \tag{36}$$

The corresponding interest rate is $1 + r = \alpha Ak^{\alpha-1}$. For this to be an equilibrium one must have $a^* < \underline{a}$, which is equivalent to (H3). Conversely, if (H3) hold, the above computations imply that the steady state with k solution to (36), and $\nu = m = 0$ satisfies all the required conditions. Finally, (33) implies that any equilibrium such that $\nu > 0$ must have a value of k smaller than the solution to (36). This implies a greater value of r. If (H3) holds, then any such steady state has a smaller value of a^*, which contradicts the assumption that $\nu > 0$. Consequently, the steady state we just constructed is the only equilibrium if (H3) holds.

Regime 2: $\nu = \underline{\nu} = (1 - bn(\underline{a}))/b$. In such a case, $L_t = N_t m\bar{a}(1 - bn(\bar{a}))$ and using again (33) and the factor price equations we see that k must satisfy

$$\left[mn(\underline{a}) + (1-m)\frac{\nu\varphi(1-\alpha)}{\alpha(1+\beta)}\right] k^{1-\alpha} = \frac{\beta(1-\alpha)A}{1+\beta}\left[m - (1-m)\varphi\frac{\nu}{n(\underline{a})}\right] \tag{37}$$

For this to be an equilibrium one must have $a^* > \underline{a}$. Rearranging and using (32) we see that this is equivalent to (H5). Conversely, if (H5) holds, the above steps imply that the steady state with k solution to (37), $\nu = \underline{\nu}$, $m = \frac{\nu}{\underline{\nu}+n(\underline{a})-n(\bar{a})}$, satisfies all the equilibrium conditions. Finally, (33) implies that any equilibrium such that $\nu < \underline{\nu}$ must have a value of k larger than the solution to (37). This implies a smaller value of r. If (H5) holds, then any such steady state has a larger value of a^*, which contradicts the assumption that $\nu < \bar{\nu}$. Consequently, the steady state we just constructed is the only equilibrium if (H3) holds.

Regime 3: $0 < \nu < \bar{\nu}$. The lowest ability agents must then be indifferent between producing output and clones, implying $a^* = \underline{a}$. This equality pins down the capital/labor ratio, which must satisfy

$$\alpha A k^{\alpha-1} = \frac{\bar{a}(1 - bn(\bar{a}))\varphi}{\underline{a}b} \tag{38}$$

ν is then determined by the steady state equivalent of (33), with L_t given by (35) and m given by (32). Using these two equations along with the factor price conditions we find that in steady state (33) is equivalent to

$$\begin{aligned} & \left[\begin{array}{c} \nu\bar{a}(1 - bn(\bar{a})) + \\ (n(\underline{a}) - n(\bar{a}))\underline{a}(1 - bn(\underline{a}) - b\nu \end{array} \right] \left[\frac{\beta(1-\alpha)}{\alpha(1+\beta)} \frac{\bar{\psi}\bar{a}}{\underline{a}b} - n(\underline{a}) \right] \\ = \quad & \nu(n(\underline{a}) - n(\bar{a})) \frac{\bar{\psi}(1-\alpha)}{\alpha(1+\beta)} \bar{a} \left[1 + \frac{\beta\bar{a}\bar{\psi}}{b\underline{a}n(\underline{a})} \right] \end{aligned} \tag{39}$$

This is a linear equation which determines ν uniquely. Furthermore, one can check that the solution is strictly between 0 and $\bar{\nu}$ if and only if (H4) holds. Conversely, if (H4) holds, the steady state with k determined by (38), ν determined by (39), and m determined by (32) satisfies all the equilibrium conditions. Since all these equations have a unique solution, it is the only equilibrium in that regime. In order for an equilibrium in another regime to exist, (H3) or (H5) would have to hold, but they are incompatible with (H4). Therefore, this equilibrium is unique. Q.E.D.

The artificial womb model

Let us assume that clones can be produced using just a quantity q of output. It is still the case that only top ability people would clone themselves, since they are the ones who generate the greatest value. Cloning will arise if and only if

$$\frac{1}{1 + r_{t+1}} \varphi y_{t+1}(\bar{a}) \geq q$$

If this inequality holds, it must hold with equality; otherwise, an infinite amount of cloning would take place. Substituting equations (12), (13), and

(7) we find that this is equivalent to

$$\frac{\psi\bar{a}(1-\alpha)}{\alpha}\frac{K_{t+1}}{L_{t+1}} \geq q$$

Because the cost of cloning is physical rather than in terms of the time of low-skill workers, its determinants are different. Cloning is more likely to arise, the greater the *absolute* value of $\bar{a}$ (rather than the ratio $\bar{a}/\underline{a}$). Furthermore, when capital is more abundant, the relative price of output in terms of wages falls, and so does the cost of cloning relative to its benefit. This makes cloning more likely. This effect is not present in the text's surrogacy model where capital accumulation equally affects the revenues from cloning and the opportunity cost of time of surrogate mothers.