The Contribution of Science and Technological Education to Citizens' Culture[1]

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Our aim in this paper is to discuss what science and technological education can bring to citizens' culture. We intend to respond to the criticism of authors who have referred to scientific literacy for all citizens as an unattainable myth, by showing that scientific literacy is both possible *and necessary* to

- foster citizens' participation in decision making about problems related to scientific and technological development
- contribute to critical thinking
- transmit the excitement of the stimulating challenges faced by the scientific community, both historically and in the contemporary world

Scientific literacy: Obvious necessity or unattainable myth?

In recent years, there has been widespread consensus about scientific literacy as an educational priority at both the individual and national level. For example, the World Conference on Science Education for the 21st Century, promoted by UNESCO and the International Science Council, declared that science and technological education is a strategic requisite for all countries aspiring to meet the basic needs of their populations. There is increasing recognition that it is necessary to raise the level of scientific literacy in all social groups in order to improve citizens' participation in decision making (UNESCO, World Conference on Science, 1999). Thus, the first page of the *National Science Education Standards*, which all citizens must attain in science in the twenty-first century, states that '[s]cientific literacy enables people to use scientific principles and processes in making personal decisions and to participate in discussions of scientific issues that affect society. A sound grounding in science strengthens many of the skills that people use every day, like solving problems creatively, thinking critically, working cooperatively in teams, using technology effectively, and valuing life-long learning' (National Research Council, 1996). Indeed, such is the importance attached to the goal of scientific literacy for all citizens that some have drawn close parallels between basic literacy at the end of the nineteenth century and scientific literacy in the twenty-first century (Fourez, 1994; Bybee, 1997; Hewson, 2002).

Given the tenor of recent debate, it may well seem unnecessary to formulate any further arguments for the incorporation of a scientific dimension into education for responsible citizenship. However, in recent years, some authors have begun to question both the possibility and the desirability of universal scientific literacy. While the most prominent work of this kind is *The Myth of Scientific Literacy* (Shamos, 1995), Atkin and Helms (1993) and Fensham (2002a, 2002b) have also produced well-documented arguments to challenge some 'obvious,' taken-for-granted assumptions about universal scientific literacy. It is crucial that science educators pay attention to the critical analysis of such authors and study more carefully and more critically the arguments used to justify proposals for seeking universal scientific literacy.

According to Fensham (2002a), the science-for-all movement and early discussion about scientific literacy were based on two major assumptions:

> First, because societies everywhere are increasingly being permeated by the ideas and products of science in the form of technologies, all future citizens will be better able to cope if they have some knowledge and confidence about science (the *pragmatic* assumption). Second, quality science education in schooling will enable citizens to participate meaningfully in the many decisions that societies and politicians must now make about complex sets of socio-scientific and socio-technical issues (the *democratic* assumption). (p. 15)

The pragmatic assumption, states Fensham, does not take into account that 'in many cases, technologies are designed so that their citizen users can bypass the science knowledge on which they are based'(p. 15). We recognize that this is a well-founded criticism: Nobody can cope with contemporary life without knowing how to read and write or without mastering the most simple mathematical operations, but millions of citizens, including well-known personalities in non-scientific fields, recognize their lack of scientific knowledge without feeling any limitation in their practical lives. This is the reason why Atkin and Helms (1993) consider that the analogy between basic literacy and scientific literacy cannot be maintained.

In respect of the democratic assumption, Fensham states that the familiar claim that the more citizens understand science, the more rationally they will respond to socio-techno-scientific issues, ignores 'the complexity of the science that is involved in issues such as global warming, cellular phone radiation's effects on health, or the conservation of endangered species' (p. 16). He concludes, 'It is a highly unrealistic hope that—even through the best of schooling—a level of science knowledge can be achieved that enables citizens to critically evaluate the scientific claims of the various expert groups' (p. 16).

Is it really an error to target citizens' participation in decision making about socio-techno-scientific issues? Must we conclude that scientific literacy is an unattainable myth and, moreover, a waste of time and effort? What, if any, could the goals of citizens' scientific education be? Criticisms such as Fensham's oblige us to delve deeper into the reasons that justify scientific and technological education as part of a general culture for all citizens. We need to analyse more carefully what scientific education *and technological education* (Fourez, 2002) can really contribute to citizens' competence. This is what we intend to do, studying, as the title of the paper indicates, what the *contribution of science education to citizens' culture* could be. In pursuit of this aim, we will discuss its possible contributions to

- citizens' participation in decision making about socio-techno-scientific issues and, more particularly, the problems that characterize the current situation of planetary emergency
- the development of critical thinking
- personal satisfaction

Contribution of scientific and technological education to decision making

The World Conference on Science Education for the 21st Century (UNESCO, World Conference on Science, 1999) and the *National Science Education Standards* (National Research Council, 1996) are good examples of the importance experts and international institutions such as UNESCO attach to citizens' literacy for decision making about socio-techno-scientific issues. This 'democratic' reason is the most widely used argument to justify scientific and technological literacy as a basic component of citizens' education (Fourez, 1994; Bybee, 1997; DeBoer, 2000). It is also the assumption most directly and explicitly questioned by Fensham (2002a, 2002b) in his assertion that the complexity of the science that is involved demands a depth of study that is only accessible to specialists.

We shall carefully analyse the lines of argument, which are certainly not trivial, that have led Fensham and others to question the science-for-all proposals. First, we need to address another line of thought that challenges even more deeply the supposed democratic value of science education because it attributes responsibility for many of the current problems humanity has to face—from diverse kinds of environmental pollution to weapons of mass destruction—to techno-scientific development itself. In painting a bleak picture of planetary emergency, this literature is generating a growing rejection of techno-science among students and contributing to doubts about the interest value of scientific literacy.

Is the current situation of planetary emergency caused by techno-scientific development?

The criticism of science and technology's contribution to the current worsening of our living conditions seems well founded. Is it not scientists and technicians, encouraged and supported by corporate executives, economists, and politicians, who produced the persistent organic polluters (POP), such as DDT, that are poisoning our planet? Was it not scientists who launched the nuclear technology that created the problem of radioactive waste that both current and future generations have to live with or try to solve? Are technological products not using the CFCs responsible for the destruction of the ozone layer? Are the internal combustion engines we produced not responsible for increasing the greenhouse effect, thereby giving rise to a climatic change that could destroy the fragile equilibrium that makes our life possible? The litany of accusations goes on!

In the contemporary world, science and technology penetrate everything we do; it is virtually impossible to think of anything, *good or bad*, in which science and technology do not play a role. Of course, the contributions of techno-science to human welfare would comprise a list as long as, if not longer than, the list of negative effects. Besides, as historian of science Sánchez Ron (1994) says, 'It is scientific knowledge that makes us conscious of some environmental problems. Would we be aware, without science, of holes in the ozone layer?' (p. 243). We should not ignore the many scientists who study the problems humanity is facing, who warn about the dangers, and who look for solutions. Not only scientists, of course, and not every scientist! The tendency to blame science and technology alone for current environmental problems is simplistic Manichaeism. Criticism and calls to act responsibly must be addressed to all of us, including those who are 'mere consumers' of damaging products (Vilches & Gil-Pérez, 2003). This is the principal argument for a science education that aims to make citizens partly responsible for decision making about techno-scientific development; it stands in stark contrast to Fensham's arguments against the possibility of a techno-scientific literacy capable of fostering citizens' responsible participation in decision making. As Désautels (2002) puts it, 'By focusing on the complexity of problems, he immediately rules out the possibility of ordinary citizens becoming involved in the socio-technical controversies with which our societies inevitably become enmeshed' (p. 189). It is imperative, then, that we analyse these arguments very carefully.

Could techno-scientific literacy enable citizens to participate in decision making?

It is our contention that citizens' participation in well-founded decision making about techno-scientific issues demands not an in-depth, specific knowledge but the union of a minimum of specific knowledge, perfectly accessible to common citizens, with global approaches and ethical commitments not requiring any specialization. It is abundantly clear that the possession of detailed knowledge, such as that of a specialist in a particular domain, does not guarantee that good decisions will be made. Approaches that contemplate problems in a wider perspective are necessary, analysing the possible impact in the medium and long-term, in the field under consideration *and in others*. This is something that non-specialists in the field, with broad perspectives and interests, can do—provided that they have the minimum specific knowledge required to understand the options and the techno-scientific arguments. From this point of view, citizens' participation in decision making is not only possible, but necessary.

The validity of this reasoning can be shown by analysis, as a paradigmatic example, of the problems caused by chemical fertilizers and pesticides in the so-called agricultural revolution following World War II. The use of synthetic substances such as DDT as insecticides and herbicides during the 1950s was denounced by Rachel Carson (1962) in her book *Silent Spring* (a title that makes reference to the unanticipated impact on birds). Providing extensive, well-founded proof of the damaging effects of DDT did not prevent her from being severely criticized and harassed by the chemical industry, politicians, and *many scientists*, who denied the validity of her evidence and accused her of being 'against progress,' particularly agricultural practices that catered for a growing population by increasing food production. Nonetheless, about a decade later, DDT was recognized as a very dangerous poison and was prohibited. The World Commission on Environment and Development (1987) recognized that its use was a menace to human health, producing congenital malformations and several forms of cancer, and that it constituted a major poison for fish, mammals, and birds. Because substances such as DDT accumulate in living tissues, they have been designated Persistent Organic Polluters (POP).

What we seek to point out here is that the battle against DDT was led by scientists such as Carson *with the help of groups of citizens* who agreed with her reasoning. In fact, Rachel Carson is remembered today as the 'Mother of the ecologist movement' (because of the enormous influence her book had in the emergence of activist groups calling for environmental protection) and as a major influence in the emergence of the STS (Science–Technology–Society) educational movement. Without the action of these groups of citizens *capable of understanding Carson's arguments*, the interdiction of DDT would have arrived much later and its effects would have been more devastating. Citizens participated in decision making by paying attention to Carson's warnings and demanding control of DDT, thereby convincing both the scientific community and legislators, who subsequently prohibited its use. It is important to recognize the contribution in this and other similar battles of *non-specialist* but scientifically literate citizens, capable of understanding scientific arguments and capable of contemplating problematic situations in a wider perspective than many specialists are prone to do. As documents of the day testify, many scientists with a much higher level of knowledge than these scientifically literate activists, could not or did not want to see the dangers associated with the use of pesticides. Many similar examples of citizens' contributions to decision making could be mentioned, such as those related to the construction of nuclear power plants and the storage of radioactive waste, the use of ozone-destroying CFCs, the greenhouse effect and the associated threat of a climatic change with devastating consequences, and the uncontrolled use of genetically manipulated plants and animals.

It is interesting to analyse briefly the example of transgenic foods—an issue that is currently generating the most passionate debate and may perfectly illustrate the role of citizens in decision making about techno-scientific issues. As we know, genetic manipulation of products such as soya beans and maize has been presented by some scientists and government officials, and especially by those enterprises dedicated to the production of genetically manipulated organisms (GMOs), as something absolutely positive, which will, among other advantages, reduce the use of pesticides and herbicides (and the consequent pollution) and make an important contribution to solving the persistent problem of world hunger. But not everybody agrees with such an optimistic view and other scientists have pointed to possible risks to the environment (due to the possible reduction of biodiversity), human health, and even the future of agriculture itself. Critics have stated that we are contemplating the widespread application of technologies that have not been sufficiently tested. In consequence, we have no reasonable guarantees against subsequent damaging effects—a situation eerily reminiscent of the DDT episode and the portrayal of DDT as the definitive solution to the problem of world hunger.

We are currently faced with an open debate, with unfinished studies and partial results, many of them presented by the producers of GMOs themselves. Disagreements among scientists and technicians are sometimes used as a reason why citizens should not participate in a debate in which not even scientists, with their higher level of knowledge, can agree. But this is precisely the reason why citizens *should* participate—in such a case, scientific knowledge is insufficient in itself for responsible decision making. The preoccupation of scientists with the technical aspects of the production and use of GMOs, coupled with doubts about the long-term environmental impact, is precisely why citizens should have the opportunity to participate in the debate. It is citizens, more than scientists, who are likely to urge caution. This is a matter not of questioning the *research* in this or any other field but of resisting the hasty application of new technologies in order to obtain the maximum commercial benefit in the shortest space of time. A more cautious approach is the aim of a growing number of consumers, now supported by an increasingly wide sector of the scientific community. It is noteworthy that this effort is having positive results: The *Protocol on Bio-security* was signed by 130 countries in February 2000 in Montreal, in spite of many previous difficulties and the pressure brought to bear by GMO producers (Vilches & Gil-Pérez, 2003). This protocol, in line with the *UN Agreement on Biological Security*, constitutes an important step forward in international legislation because it obliges companies *to prove* the security of products before commercializing them (Vilches & Gil-Pérez, 2003). In this way, we may avoid the kind of serious mistakes we made in the past. Sadly, some countries (most notably, the United States) have still not signed it.

This rejection of technological innovations whose medium- and long-term effects remain unknown does not imply any hindrance to the development of research or to the introduction of well-tested innovations. For instance, ecologist opinion is not opposed to research with embryonic 'mother cells.' On the contrary, in many countries, ecologist associations support the scientific community's fight against the current interdiction of this research in response to pressure from fundamentalist lobby groups. Citizen participation in decision making should be seen as entirely positive, a guarantee of the application of the precautionary principle. It reflects growing social sensitivity to the risks of insufficiently tested innovations and the pursuit of short-term private interests at the expense of the wider public good.

To make responsible participation a reality, the problems and options need to be well understood by everyone. Of course, this entails a minimum level of scientific literacy on the part of all citizens. It also requires that the relevant issues be presented to the public in readily accessible language rather than that public participation be discouraged by an emphasis on the great difficulty and complexity of problems such as the greenhouse effect or climate change. Of course, profound and rigorous scientific studies are needed, but they are not sufficient in themselves to ensure good decisions. Frequently, the greatest difficulty lies not in a lack of knowledge but in the absence of a global approach that can assess risks and analyse possible effects in the medium and long term.

These are the reasons why we stand for the techno-scientific literacy of *all* citizens—a literacy that has become an absolutely necessary in the current situation of *planetary* *emergency* (Bybee, 1991; Orr, 1995), marked by an array of very serious and closely related problems: pollution and environmental degradation, depletion of natural resources, unsustainable demographic growth, extreme inequalities among human groups, destructive conflicts, loss of biological and cultural diversity, and so on. This planetary emergency is largely driven by the pursuit of short-term private benefits, without taking into account the consequences for others or for future generations (Gil-Pérez et al., 2003).

In spite of many appeals, such as those by the United Nations at the Earth Summits in Rio (United Nations, UN Conference on Environment and Development, 1992) and Johannesburg (United Nations, UN Commission on Sustainable Development, 2002), we educators are not, generally speaking, paying enough attention to this situation. Although there is an important role for informal education (museums, science centres, newspapers, television, and other media) in contributing to a better-informed perception of the state of the world and preparing citizens for responsible decision making, the key role in ensuring universal techno-scientific literacy is that of the formal education system, from elementary school to university. A redirection of science education towards this goal is particularly important, given the nature of many of the issues. This redirection seems particularly urgent in light of the recent United Nations initiative for a 'Decade of Education for Sustainable Development' from 2005 to 2014 (UNESCO, 2005).

Instead of being regarded as an 'unattainable myth' (Shamos, 1995), scientific literacy *has to become* an essential dimension of citizens' culture. This conclusion is not the fruit of a preconception accepted uncritically, as alleged by Fensham (2002a, 2002b). Quite the contrary, the real preconception has been, and continues to be, that most people are incapable of acquiring scientific knowledge because of its high cognitive demand, with the *obvious* implication that it should be restricted to a small and elite group. In our view, rejection of the goal of universal scientific literacy echoes the systematic historical opposition of privileged people to the extension of culture and the generalization of education. Our demand forms part of the battle of progressive forces to overcome this anti-democratic preconception. In this respect, we cite the great French scientist Paul Langevin (1926), who pointed out that revolutionary movements always advocate science as part of general education because they recognize the role it plays in the liberation of minds and in the confirmation of human rights. Taking our lead from Langevin, we argue that the main contribution of science education to citizens' culture is the *development of critical awareness*.

How science education can contribute to citizens' critical awareness

In contrast to Langevin's belief that education in science can liberate the mind, equipping people to question dogma and defy authoritarianism and privilege, many students regard science as primarily focused on the presentation of esoteric, abstract knowledge of little interest to the average citizen. Given the way that science is taught in many schools, it is not surprising that students ask, Why would we be interested in abstract and purely formal subjects like mechanics? We can, and must, do it differently. An approach via the history of science, for example, is capable of showing students the real adventure of science, the exciting and passionate battle for freedom of conscience, thought and research, in the face of social restriction and religious persecution. The reinstatement of the historical dimension and the injection of a science–technology–society–environment (STSE) approach can bring vitality to science education and play a key role in fostering the critical awareness we seek. The debates surrounding heliocentrism, evolution, organic synthesis, and the origin of life, for example, together with the current battle for sustainable development, constitute excellent case studies.

Science learning can become an adventure capable of strengthening critical awareness in a deeper sense: the adventure of confronting open-ended, problematic situations and of participating in the tentative construction of solutions—in short, the adventure of *doing* science (Gil-Pérez & Carrascosa, 1985, 1994; Hodson, 1992). A serious impediment to achieving this goal is that science education often presents a distorted and impoverished view of science as a rigid activity carried out by white-coated, dispassionate individuals working in ivory-tower laboratories (Gil-Pérez, 1993; McComas, 1998). These distortions are usually justified by teachers as necessary in preparing students to work as scientists and technologists. It is commonly argued that preparing specialists in biology, physics, and chemistry necessitates an approach focused on the concepts, principles, and laws of these disciplines. At the same time, science education for responsible citizenship (with its emphasis on STSE issues and the development of critical awareness) is seen as an alternative form of education for non-specialists. The pursuit of citizens' education *instead of* the training of future scientists generates considerable opposition among those who argue, legitimately, that society needs scientists and technicians. Why can we not do both? It is our contention that the critical awareness we seek for non-specialists is just as important, possibly more important, for future scientists. It is also our contention that a science education focused exclusively on the conceptual dimension is equally negative for the education of future scientists and technicians. As we have already pointed out, this orientation transmits a distorted and impoverished view of science that not only diminishes the interest of young people in scientific careers (Matthews, 1991; Solbes & Vilches, 1997) but negatively affects conceptual learning. Together with Hodson (1992), we contend that 'students develop their conceptual understanding and learn more about scientific inquiry by engaging in scientific inquiry, provided that there is sufficient opportunity for and support of reflection' (p. 551). If we are to achieve a meaningful understanding of concepts and theories, we must reorganize science learning into an activity that integrates conceptual, procedural, and axiological dimensions (Duschl & Gitomer, 1991). This paves the way for a more creative, open, and socially contextualized view of science, in accordance with the real, tentative nature of techno-scientific activities (Gil-Pérez et al., in press), in which critical awareness and questioning of what seems 'natural' and 'obvious' plays an essential role.

The pursuit of scientific literacy should be seen not as a deviation or reduction making science accessible to the population as a whole but as a reorientation of teaching also useful for future scientists—useful to modify the current socially accepted but distorted view of science and to fight against anti-science movements; useful to facilitate meaningful conceptual learning. In other words, we reject the notion that the usual conceptual reductionism constitutes an obstacle to citizens' literacy *but* a requisite for the preparation of future scientists and technicians. In our view, it is an obstacle *for both*. This convergence can be appreciated more clearly by considering Bybee's (1997) thesis that citizens' techno-scientific literacy demands *immersion in a scientific culture*.

Immersion in a scientific culture as a way of fostering critical awareness and acquiring scientific knowledge

Bybee (1997) reminds us that the most efficient way of gaining literacy in a language is through sociocultural immersion. Similarly, he suggests, immersion in the scientific culture constitutes an excellent means of acquiring scientific literacy. Acceptance of this position carries with it the notion that teaching strategies should be oriented towards involving students in the (re)construction of knowledge—that is to say, aligning their activity more closely with the richness of the techno-scientific treatment of problematic situations. In other words, learning should be organized as a guided research and innovation activity focused, for the construction of scientific knowledge, on the treatment of interesting problematic situations and on the attainment of technological innovations conceived to satisfy particular needs. In this way, learning becomes an open and creative activity of novice researchers, appropriately organized by the teacher acting as an expert researcher. Such activity, which overcomes conceptual reductionism, incorporates the multiplicity of aspects enumerated below (Gil-Pérez et al., 2002):

- *Discussion of the desirability of studying the situations proposed*, taking into account the social and environmental impacts, the possible contribution to the comprehension and transformation of the world, and so on. The goal is to avoid the all-too-common situation in science education where students are required to study a topic designated by the teacher, without having the least motivation for doing so. Through discussion, students will have the opportunity to practise decision making about whether (or not) they undertake a particular research or innovation activity (Aikenhead, 1985).
- *The qualitative study of the situations proposed*, taking decisions—with the help of the necessary bibliographic research—to define and delimit concrete problems. If we want students to understand what they are doing, it is essential to begin with qualitative and meaningful approaches—just as scientists themselves do.
- *The invention of concepts and the forming of hypotheses* as tentative answers, founded on students' previous knowledge and personal conceptions. This will help to focus the problems to be studied and guide their treatment.
- *The elaboration and implementation of possible strategies for solving the problems*, including, where appropriate, experimental designs to check hypotheses. It is necessary to highlight the interest of these designs and the implementation of experiments which demand (*and aid in developing*) a multiplicity of knowledge and skills, including technological work to solve the practical difficulties usually posed by designs.
- *The analysis and communication of results*, comparing them with those obtained by other student teams and the scientific community. This can produce cognitive conflicts between different conceptions and demand auto- and inter-regulation—that is to say, the formation of new hypotheses and the reorientation of the research. It is particularly important to emphasize communication—reading and writing scientific reports and engaging in oral discussions—as an essential aspect of scientific and technological work.
- *The recapitulation of the work done*, connecting the new constructions with the body of knowledge already possessed and paying attention to establishing bridges between different scientific domains.
- *The contemplation of possible perspectives*, such as the conception of new problems or the realization and improvement of technological products, both of which can contribute to the reinforcement of student interest. This allows the student to deepen and consolidate new knowledge by applying it in a variety of situations, putting special emphasis on the STSE relationships that frame both scientific development and human development and focusing attention on the current planetary emergency (Gil-Pérez et al., 2003).

It should be emphasized that these orientations do not constitute an algorithm to guide student activity step by step. Rather, they should be seen as generalizations intended to draw attention to essential aspects of the construction of scientific knowledge that are currently insufficiently taken into account. We are referring both to procedural and to axiological aspects, such as STSE relationships (Solbes & Vilches, 1997), decision making (Aikenhead, 1985), communication (Sutton, 1998), and the like, that we consider essential to creating a climate where student teams, acting as *novice researchers*, undertake collective research with the teacher's more expert assistance. In this way, pupils participate in the (re)construction of knowledge and learn more meaningfully (Hodson, 1992; Gil-Pérez et al., 2002). This open and creative approach allows the immersion of future citizens in the techno-scientific culture *necessary* for (a) the education of critical citizens who can participate in decision making without being prisoners of the 'evidence' provided by others, of what has 'always been done,' or of authoritative arguments; and (b) the education of the future scientists and technicians our society requires.

Scientific culture as a source of enjoyment

We have argued that techno-scientific literacy is necessary for the attainment of two basic aims that are *initially convergent*: the development of citizens' critical awareness *and* the education of future scientists and technicians (who will emerge from a techno-scientifically literate population in greater number and be better prepared). We also draw attention to a third and very important reason for the universalization of scientific education, a reason that goes well beyond its usefulness. We refer to the *enjoyment* that scientific constructions can provide. In particular, science amplifies our vision of the universe, shedding light on its past and future. This helps us to understand phenomena that have threatened humanity during previous centuries, frees us from prejudices, and transmits the excitement of stimulating challenges.

For Fensham (2000a), the capacity of science as a source of excitement and wonder should be the basis of the science-for-all curriculum: 'Only as all students have the opportunity to encounter these features of science will enough of them be attracted to undertake, for good intrinsic reasons, the more systematic study of science that leads on to scientific careers' (p. 22). We endorse the importance of excitement, wonder, and enjoyment in science education—in fact, in any education! Our point is that enjoyment is a crucial element in preparing for decision making about techno-scientific issues. Do we not already know that, for many students, the greatest enjoyment is associated with action rather than with mere contemplation? Does participating in the solution of a challenging problem not produce greater satisfaction than simply learning what others have done? Is it not a source of satisfaction to contribute, as responsible citizens, to our future orientation? It is our contention that the enjoyment of scientific culture is a right that we have to promote fully through a science program that extends well beyond mere contemplation.

Note

1 This paper has been conceived as a contribution to the Decade of Education for Sustainable Development, established by the UN General Assembly for the period 2005–2014.

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