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Does modern ICT enable more efficient economic models?

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1 Introduction and motivation

Money is a fundamental expression of today's economic system. It is the universal medium of exchange, and as such, it is the ultimate container of value, although its use value (its direct utility in satisfying any need) is equal to zero. It is also an expression of wealth and it is, in particular, tied to the concept of free exchange.

Money is used to compensate men for labor and it's generally assumed that without this kind of reward the economic system would prove to be very inefficient. The reason is that men need money as a motivator to work. While this is likely true for repetitive and mindless tasks, it seems to be completely wrong with respect to creative and interesting tasks. Here money turns out to be even counterproductive.[1] When considering the fact that technological progress, in particular automation, is constantly reducing the demand for repetitive and mindless jobs, the need of money as a motivator could be called into question.

Moreover, many problems afflict the world today and they cannot be said to be completely decoupled from the economic system governing us. In particular, the unequal distribution of wealth and the environmental sustainability problem are undoubtedly two of the most serious global issues of our time.

With regard to the former, according to recent estimates,[2] the richest 1% of world's population owns 48.2% of global assets. The top 10% alone holds 87% of world's wealth, while the bottom half of global population gets less than 1% of the pie. This condition isn't caused only by disparities between countries or within developing countries, but also within many western countries. In Switzerland, for instance, the richest decile of the inhabitants accounts for 71.9% of national assets.[3] Considering the distribution of income instead of wealth, the situation isn't any better; from 1820 to 2000 the world income Gini coefficient[4] grew by 17 points – from 49 to 66.[5] But it must not be forgotten that the worst expression of inequalities is certainly poverty and that this issue is far from being resolved. Still in 2011, nearly 17% of world's population lived with less than 1.25$ per day,[6] the international threshold of extreme poverty.

Regarding the long term sustainability of the today's production system, the issues at stake are summed up perfectly in the following quote:

> From climate change to resource overconsumption to pollution, the engine that has powered three centuries of accelerating economic development revolutionizing technology, science, culture, and human life itself is, today, a roaring out-of-control locomotive mowing down continents of forests, sweeping oceans of life, clawing out mountains of minerals, drilling, pumping out lakes of fuels,

[1] D. Pink, *Drive: The Surprising Truth About What Motivates Us*, Riverhead Books, 2009.
[2] *Global Wealth Report 2014*, Credit Suisse Research Institute, 2014.
[3] *Global Wealth Report 2014*, Credit Suisse Research Institute, 2014.
[4] The Gini coefficient is a measure of the inequality of a distribution, where 0 means perfect equality (for instance, all individuals have the same income) and 100 means maximal concentration (one individual gets the whole income).
[5] *Breaking the camel's back*, The Economist, 2014 Oct 4. Citing a study of OECD and University of Utrecht (2014).
[6] World Bank data. Available from http://iresearch.worldbank.org/PovcalNet/index.htm?1

> devouring the planet's last accessible resources to turn them all into "product" while destroying fragile global ecologies built up over eons of time.[7]

In light of the above considerations, this thesis aims at investigating *technical possibilities for moneyless, fairer and more efficient economic models enabled by today's information technology*. Such models are typically found on the concept of "planned economy", although the planning is executed in a more decentralized fashion than commonly interpreted. This allows for the involvement of many actors in the decision making process, giving them decision possibilities that in a free market environment are usually prerogative of only a few. For instance, it could be possible to reverse the sequence of action of supply and demand that we normally observe in a free market environment, where production acts first driven by the figure of the entrepreneur – gathering the demand first (for instance, by means of online surveys) would allow to subsequently arrange the production and the distribution on a fairer basis. On the other hand, planned economy has many arguments against its efficient practicability, such as the famous "economic calculation problem".

Thus, the first part of the thesis investigates arguments supporting the necessity of money to organize and economize efficiently. Second, an alternative model developed by Cockshott and Cottrell in 1993 is illustrated and discussed with regards to the problems stated in the first part. Third, an overview of potential for modern information and communication technology to enable non-monetary economic models is presented. In conclusion, since (as stated above) a non-monetary economy will require some sort of planning, and in consideration of the affinity of purpose, some real experiences of planned economies, their downsides and their relationship with information technology are investigated.

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[7] R. Smith, *Capitalism and the Destruction of Life on Earth: Six Theses on Saving the Humans*, 2013 Nov 10 (last visited 2014 Dec 2). Available from http://truth-out.org/opinion/item/19872-capitalism-and-the-destruction-of-life-on-earth-six-theses-on-saving-the-humans

2 Arguments against planned and moneyless economy

2.1 Economic calculation problem

The economic calculation problem was stated for the first time by Ludwig von Mises in 1920.[8] Economic calculation is the concept that allows us to undertake rational choices regarding production activities. In order to perform economic calculation, men need to judge the value of the various economic elements they are concerned with. For instance, when deciding to construct automobiles one needs to know that employing a certain production process or a certain material is more convenient with respect to other possibilities. Human mind can judge the value of only very simple processes. In fact, when conditions become more complex and the interconnections are not so easily discernible – for instance, when the choice to be made include many and very lengthy production processes – human mind is not able to take a rational choice without the aid of more sophisticated calculation means. Mises makes the following example:

> But it is quite a different matter when the choice lies between the utilization of a water-course for the manufacture of electricity or the extension of a coal mine or the drawing up of plans for the better employment of the energies latent in raw coal. Here the roundabout processes of production are many and each is very lengthy; here the conditions necessary for the success of the enterprises which are to be initiated are diverse, so that one cannot apply merely vague valuations, but requires rather more exact estimates and some judgment of the economic issues actually involved. [9]

Monetary calculation allows us to undertake these choices in a rational manner. Indeed, according to Mises, monetary prices are based upon the subjective valuation of all participants in trade, and therefore they represent the social economic value of commodities. Everyone can base his decisions regarding capital goods and intermediate goods on this value. Prices provide a control over the appropriate employment of goods – people have a basis for working more economically as possible. They try to minimize their monetary costs, which represent economic costs. In this sense, monetary calculation:

> affords us a guide through the oppressive plenitude of economic potentialities. It enables us to extend to all goods of a higher order the judgment of value, which is bound up with and clearly evident in, the case of goods ready for consumption, or at best of production goods of the lowest order. It renders their value capable of computation and thereby gives us the primary basis for all economic operations with goods of a higher order. Without it, all production involving processes stretching well back in time and all the longer roundabout processes of capitalistic production would be gropings in the dark. [10]

But if money is removed from the system, or if it loses its common meaning, the basis for monetary calculation disappear. Once production means aren't exchanged by entrepreneurs interested on their value, meaningful prices cannot form. Therefore, it's

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[8] L. v. Mises, *Economic Calculation In The Socialist Commonwealth*, Ludwig von Mises Institute, 1990. First publication of the article dates 1920.
[9] L. v. Mises, *Economic Calculation In The Socialist Commonwealth*, p. 9.
[10] L. v. Mises, *Economic Calculation In The Socialist Commonwealth*, p. 11.

impossible for planners in a non-market economy to evaluate what process or material is more economical than others on the basis of monetary values.

However, money is not necessarily the only possible means apt for economic calculation. Two alternative proposals are calculation in kind and calculation in terms of labor. The former is the method of accounting based on physical quantities of the various items. A common argument against calculation in kind is that it doesn't provide a real alternative method of evaluating the cost and the benefit of producing a certain good. Indeed, it's hard to imagine that pure technical considerations could suffice to determine the economic efficiency of a given production process. As for calculation in terms of labor Mises argues that it ignores the cost of scarce non-reproducible resources and the different qualities of different labors.[11]

In conclusion, it is clear that the knowledge of costs and benefits of production processes is important in a planned economy, as much as it is in a free market one. Obviously, the general framework must be different, but it will anyway require a method of evaluating the efficiency of a product in meeting social needs, and the social costs generated in its production. In addition, this method must enable the comparison of different production processes on the same basis. Without such a method, no conception of rationality or efficiency is possible.

2.2 Distribution of consumption goods

In a moneyless context, the distribution of consumption goods cannot be made upon the basis of monetary prices. Therefore, another system of distribution has to be chosen. The matter would be very simple, if the total demand of the population could be gathered with a survey system, and the needed amount of every good could be actually produced in the needed time. However, if the economic system must be efficient and a certain amount of free choice must be granted to the consumers, such a system proves to be impracticable. In fact, if it could be true that human needs are finite, human desires aren't. In particular, in the context of leisure goods, one individual could require for his personal use considerably high amounts of certain goods or services, and it's obvious that their production would always generate social costs.

Rationing – just like Switzerland (and many other nations) did during World War II – could be an alternative. Every member of the community receives an equal amount of coupons, redeemable within a certain period against a definite quantity of certain specified goods. However, having individuals different preferences, after they have redeemed their coupons, they will start to exchange some goods in place of others, and an exchange market will arise. This system could provide to the planners information about changes in demand. If, for example, on the market a cigar is exchanged against three cigarettes, when before the same cigar was equal to two cigarettes, one must conclude that the demand for cigars among the population is increased. Therefore, the planners could try to adjust the production accordingly to these data. However, this system isn't a favorable solution for consumers. Indeed, they cannot choose the products they desire on the first

[11] L. v. Mises, *Economic Calculation In The Socialist Commonwealth*, pp. 19-22.

hand, but are forced to exchange the assigned products – a significant complication. In light of this consideration, it would therefore make no sense to abolish every kind of money. Indeed, “the same grounds which have always existed for the building-up of indirect exchange will continue […] to place advantages in the way of those who indulge in it”.[12]

Finding the appropriate distribution system for a moneyless economy is a task more difficult than at first sight it may appear. We need a system that allows consumers to express their preferences, but at the same time consumers should understand (and somehow contribute to) the social cost generated by the production of requested goods or services.

2.3 Innovation and technical progress

Another common objection against the idea of planned economy is that it lacks incentives regarding innovation. Innovation is the process that enables technical progress, and it is desirable that the economy provides an efficient framework for technical progress, given its importance in increasing human welfare.

To analyze an economic system with respect to its dynamic efficiency, the following questions are helpful:[13]

1. Does the system provide strong incentives for innovation?
2. Does the system provide substantial means to carry out innovation?
3. Does the system generate innovative effort that contributes effectively to the improvement of human welfare?

A free market economy is commonly considered to be more efficient in providing incentives for innovation, due to the principle of free enterprise and the material rewards that can be earned by innovators. However, according to Kotz,[14] the profit incentive of capitalism is profoundly contradictory when considering the innovation process. In fact, in order to get their monetary reward, innovators must gain monopoly control over their inventions. Patents were conceived exactly for this purpose. The contradiction is that, on the other hand patents prevent the rapid diffusion of the innovation.

In addition, Kotz argues that the capitalist innovation process has its greatest flaw when considering the effective contribution to human welfare. In this respect, he identifies the following problems:[15] 1) innovations are disproportionally directed at upper income consumers; 2) public goods are largely ignored in the innovation process; 3) external benefits and costs of innovation, which may loom very large, are not taken into account in innovation decisions; 4) the monopoly power required to stimulate innovation leads to high monopoly prices for the resulting product, limiting the use of the new innovation and hence reducing the benefit from it; 5) much innovation activity is pure waste, as firms devote innovation resources toward the end of defeating rivals rather than benefitting consumers.

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[12] L. v. Mises, *Economic Calculation In The Socialist Commonwealth*, p. 5.
[13] D. Kotz, *Socialism and Innovation*, University of Massachusetts, 2000, p. 3.
[14] D. Kotz, *Socialism and Innovation*, p. 4.
[15] D. Kotz, *Socialism and Innovation*, p. 4.

However, if capitalism maybe doesn't provide the perfect framework for innovation, it does not follow that a planned economy does it – the incentive problem is a serious issue. Thus, in section 3.5, the alternative system will be analyzed on the basis of the above three questions and compared with the capitalistic one.

3 Cockshott and Cottrell's model

3.1 Labor time as measure of cost

In Cockshott and Cottrell's model, labor time becomes the unit of account and the measure of cost. "The allocation of resources to the various spheres of productive activity takes the form of a social labor budget" and "the principle of labor time minimization is adopted as the basic efficiency criterion".[16] They refuse the claim of Mises that labor time doesn't take into account the exploitation of non-reproducible resources, arguing that marginal labor time needed in obtaining scarce resources increases as the resource is consumed. In addition, they claim that the planners could always decide to investigate alternatives and that markets as well don't offer a solution to the problem.

The labor embodied in a product is calculated summing up the direct and the indirect labor required to produce it. For example, consider a machine for producing screws which cost 200 labor hours.[17] The machine is assumed to work 2000 hours before being substituted for obsolescence. Thus, the machine transmits $\frac{200}{2000} = 0.1$ labor hours during every hour it is running. If its output consists of 5 screws per hour, then every screw gets $\frac{0.1}{5} = 0.02$ labor hours of value added by the machine. This is the indirect labor needed in the production of a screw. If operating the machine requires in addition two full time workers, representing the direct labor in the process, than the final cost of a screw is:

$$0.02 + \frac{2}{5} = 0.62 \; labor \; hours$$

However, it's not that easy to get the cost in labor hours of every good in the whole economy. The machine in the example above was likely produced by other machines and so on. We could even find problems of circularity, for instance when a certain good is used in the production of itself. To deal with this complex interdependence an input-output table can be used. An input-output table shows how the output of an industry is used as input in others, as shown in table 1.

Table 1: a simple input-output table.
Iron expressed in tons, bicycles in unit, workers (human resources) in person-weeks.

Industry	**Inputs**			**Gross outputs**
	Iron	Bicycle	Workers	
Iron production	4,000	0	2,000	**50,000**
Bicycle production	200	0	1,000	**30,000**
Total intermediate	**4,200**	**0**		

For example, 4,000 tons of iron and 2,000 person-weeks are used in the production of iron, resulting in a gross output value of 50,000 tons of iron. "Gross output" is the total

[16] P. Cockshott, A. Cottrell, *Economic planning, computers and labor values*, 1999, p.2. Emphasis added.
[17] For now, let us assume that the cost is given.

quantity of a certain good produced in the economy, and it's composed of "intermediate output" plus "final output" (sometimes called "net output"). Intermediate output stands for products that will be used within the productive system itself (for instance, in the above example, the iron used to produce bikes or to produce other iron). Final output is the portion of gross output remaining, intended for final use (consumption and net investments). If we draw up an input-output table of the whole economy, we can build a linear equation system and calculate the labor cost of any product. We only need the following formula:

$$v_i = \lambda_i + a_{i1}v_1 + a_{i2}v_2 + \cdots + a_{in}v_n$$

where v_i is the value of good *i*, λ_i is the direct labor required to produce one unit of good *i*, and a_{ij} is the technical coefficient representing the input of product *j* required to produce one unit of good *i*. Technical coefficients specify the input-output ratio between two products. For instance the technical coefficient of iron input in the production of itself is $\frac{4{,}000}{50{,}000} = 0.08$. If there are millions of products the linear equations system can be huge but not impossible to crack as shown in section 4.3.

A final note on skilled labor: skilled labor is treated the same way as any other product – it's evaluated in terms of training cost required to produce it. Training cost determines the "skilled labor multiplier". The higher the cost of training, the higher the skilled labor multiplier. For instance, an engineer could have a skilled labor multiplier of 1.3 meaning that he "transmits" to its product 1.3 labor hours during every hour of work.[18]

3.2 Labor token system of distribution

In principle every person is rewarded with one "labor token" for every hour worked, with no difference between different jobs – a basically egalitarian pay system. However, in fact, a flat tax is withheld to offset communal uses of means of production, such as investments in production infrastructures, the creation of public goods and services, and the support to those unable to work. Labor tokens are nominal, that is, they can only be spent by the worker who received them. Skilled and unskilled workers is given the same reward for each hour of work, without considering if a work "transmits" more labor than another; the transmission-rate seen in 3.1 is only necessary for accounting the social cost of goods and services produced by a certain worker. We must consider that workers are paid also during their educational period, because they are considered to be training for the benefit of the society.

The distribution of goods and services takes place on the basis of labor time value. Goods and services are initially "sold" by the administration at their labor time value against labor tokens. For instance, the screw seen in section 3.1 is "sold" at 0.62 labor tokens. Then, prices are adjusted by the administration on the basis of demand and supply in the short run, so that they should reflect market-clearing prices. For example, if too many screws are asked, then the price of a screw will be increased. Instead, if demand for screws is too low, the price of a screw will be lowered. Consequently to changes in prices, planners decrease

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[18] For further explanation see P. Cockshott, A. Cottrell, *Towards a new socialism*, digital version, 1993, pp. 39-40.

the production of goods less demanded, and raise the production of goods more demanded, with the purpose of achieving equality between the objective labor time cost of production and the subjective valuations of consumers. Once this equilibrium is achieved, we can say that the social value of a good is equal to the social labor time necessary for its production.

3.3 Resource allocation

When planners want to change production volumes – either because prices must be adjusted or because the citizens decided to make specific investments – they need a system to evaluate if the current production capacity is sufficient to reach the target output. One can use a method based on the input-output table of the whole economy (similar to the method seen in 3.1). This method evaluates the gross output of every product needed to achieve a certain set of final outputs. If the required gross output can actually be produced with the current production means, then the target final output can be achieved. Otherwise, planners set another target set of final outputs (they cut the less important products) and try again. The method is further explained in section 4.3.

In addition, Cockshott and Cottrell wrote an algorithm based on neural nets, which evaluates the harmony of the whole economy. The algorithm has iterative form and calculates the feasible set of final outputs that maximize the harmony.[19]

3.4 Democratic decisions on major allocation questions

"The allocation of social labor to the broad categories of final use (accumulation of means of production, collective consumption, personal consumption) is suitable material for democratic decision making."[20] The forms suggested are "direct voting on specific expenditure categories at suitable intervals (e.g. of whether the social labor devoted to the health care system should be increased, maintained or reduced), voting on a number of pre-balanced variants or electoral competition between parties with different thought regarding planning priorities."[21]

3.5 Concerning the issues in 2

In Cockshott and Cottrell's model economic calculation is handled with the aid of two concepts – the use of labor time as measure of cost, and the allocation of resources by means of an input-output calculation (which can be based on a special harmony algorithm). It should be noted the fundamental role of computational power related to this purpose, as explained in section 4.3.

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[19] For a more in-depth treatment see P. Cockshott, A. Cottrell, *Economic planning, computers and labor values*, University of Glasgow and Wake Forest University, 1999, pp. 5-7.

[20] P. Cockshott, A. Cottrell, *Economic planning, computers and labor values*, p. 3.

[21] P. Cockshott, A. Cottrell, *Economic planning, computers and labor values*, p. 3.

With regard to the distribution of consumption goods, they succeed in avoiding the creation of an exchange market between consumers, while at the same time their distribution model allows consumers to express their preferences about goods and services. In addition, since the price of goods is adjusted in the short term, they also avoid the possibility of shortages and undesired surpluses in supply. As seen before, the willingness to pay of consumers provides a useful basis to evaluate the social utility of a certain good. Moreover, since this value has the same unit of measurement – that is, labor time – as cost, comparison between the two can be easily made.

Concerning innovation, we must recall the three questions exposed in section 2.3. First, an economic system should provide incentives for innovation. The conception of an innovative idea and its development often take place in appropriate institutions, where monetary incentives aren't normally so strong. In addition, this thesis started exactly from the consideration that monetary rewards doesn't incentivize creative and interesting task,[22] which are likely the most needed when innovating. It's not difficult to imagine that universities or special research institutions could play an important role also in Cockshott and Cottrell's model. However, innovation needs also to be accepted and diffused by those governing the production system. In this regard, managers of planned economies are often reluctant to introduce innovation, given the high risks that the process involves. A solution could be the introduction of a reward system for managers that succeed in constantly decreasing the labor time required in their enterprises. Unfortunately, Cockshott and Cottrell don't spend much time with this issue.[23]

Second, the economic framework must provide substantial means for innovation. With regard to this point, it must be noted that the means granted to research institutions would be decided democratically by the citizens. We can also envisage a technical committee with the role of evaluating special ideas developed by individuals outside from the institutional framework. Such ideas could be also material for democratic choice. In addition, managers that would like to implement a certain innovative project could request special resources that will be grant only to the more suitable projects.

Third, will innovation contribute effectively to the improvement of human welfare? Probably yes. Since innovation will for sure be directed in a more democratically way, all the problems of capitalistic innovation cited in 2.3 will likely disappear.

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[22] D. Pink, *Drive: The Surprising Truth About What Motivates Us*, Riverhead Books, 2009.

[23] Their views about this issue are mostly exposed in P. Cockshott, A. Cottrell, *Towards a new socialism*, digital version, 1993, pp. 33-34 and 117-119.

4 Role of ICT

4.1 Distributed decision making and democracy

Today's telecommunication systems enable real time information exchange at a very high speed and at a very small cost. In Western countries the network is already wide implemented and it remains few people without an internet connection. This level of diffusion enables new paradigms for democracy. When considering a planned economy, a planning authority could take advantage of telecommunication network for gathering consumers' preferences. For instance, every person answers an online questionnaire on a periodic basis, specifying its preferences about food, clothes, interior design, and so on. In addition, they could be asked to give indicative data about what will their future purchases be in the forthcoming time period.

However, even at the present moment, in a market environment, telecommunication technology is at the root of democracy changing developments. One example is remote electronic voting. In Canada, internet voting is used in 97 municipalities for local elections,[24] while in Switzerland many pilot projects have already took place in the latest years. [25] The development of secure electronic identification plays a key role in this field.

But we shouldn't forget that in addition to giving their opinion, people can also be reached by much more information on public affair. If at first sight this seems a democracy-enabling argument, it should be noted that this could be a double-edged sword. In fact, since sharing and spreading information is easier than ever, the same thing could be said with respect to disinformation. Today's information and telecommunication technology has undoubtedly the potential for a largest democratic participation in many more issues than commonly understood. Direct democracy could be extended to many more public affairs already nowadays. However, its right application isn't guaranteed a priori, and its legal control is more difficult than that of more "classical" communication systems.

4.2 Management at enterprise level

Back-end information systems, supporting internal processes of the firm, such as production and accounting, and front-end systems, creating interfaces to the external world, are nowadays often put together in so-called "enterprise resource planning" (ERP) systems. These systems are aimed at integrating all the most important enterprise processes and at enabling data exchange within the firm but also with external actors. Such systems could be useful also in a planned economy framework; enterprise data could be constantly collected and sent to the central planner or horizontally to other enterprises.

Integrated in ERP are often "Decision support systems" (DSS) – systems that analyze huge amount of data and display results with the most advanced visualizations techniques,

[24] http://www.internetvotingproject.com
[25] http://www.bk.admin.ch/themen/pore/evoting/06552/index.html?lang=de

with the purpose to provide useful information for manager. In addition, many ERP systems have very advanced asset management functionalities, which provide in-depth data about asset status. Even the whole lifecycle of a production plant can be managed with this kind of software. Furthermore, industrial plants are largely automatized, and they can be very flexible to production volume – production techniques such as "just-in-time" would be very useful in a non-market context. With today's technology it would be also possible to trace a production process from start to end, as well as products flows. For instance, right now, in many countries every product is uniquely identified by means of "universal product codes".

ERP systems already exist nowadays and they play an important role in business administration. After some little adjustment, their role could be very important in a planned economy too.

4.3 Computational economics and simulation

Computational economics is a field of study at the intersection between computer science and economics, dealing in particular with the computational simulation of economic systems. The number of researches on this topic is huge, although the largest part is obviously addressed at modelling market environments. However, the simulation of input-output models, employed in the analysis of market economies, could be very useful to a planned economy too. It provides an effective method for dealing with the multitude of intermediate outputs and therefore a first solution to face the economic calculation problem. As argued in 3.3, this type of simulation provides a forecast of changes in gross output, when new quantities of final output are desired. This calculation is based on the values of multipliers of the various production functions. For instance, let us assume a very little economy with only four types of goods, namely bread, coal, corn and iron.[26] In order to make bread, corn (for the flour) and coal (to bake it) are required. To grow the corn we need seed corn and iron tools. In order to make iron, both coal and iron implements are used as inputs. The mining of coal also requires both coal and iron. Further, we assume the following production functions with the relative multipliers[27]:

0.05 ton iron + 2 ton coal → 1 ton iron
0.2 ton coal + 0.1 ton iron → 1 ton coal
0.1 ton corn + 0.02 ton iron → 1 ton corn
1.5 ton corn + 0.5 ton coal → 1 ton bread

[26] This example is taken from A. Cottrell, P. Cockshott, G. Michaelson, *Is Economic Planning Hypercomputational? The Argument from Cantor Diagonalisation*, 2007, pp. 11-13.

[27] Multipliers can be estimated with various methods. A very simple – but rough – one consists in analyzing statistical data of the economy in a given time frame. For instance, if in 2013 Switzerland iron sector produced 50,000 tons of iron which required 5,000 tons of coal and 2,500 tons of iron as input, we could set the multipliers of the iron production function to 0.1 for coal and to 0.05 for iron itself. A more sophisticated method could take into account disaggregated data from different enterprises, their load and the state of technology.

With this information we can now build a system of linear equations aimed at evaluating the gross output required for producing a given target set of final outputs. The gross output of a certain good can be calculated with the following formula:

$$G_i = I_{i1} + I_{i2} + \cdots + I_{in} + F_i$$

where G_i is the gross output of good *i*, I_{ij} is the amount of good *i* used in the production of good *j* and F_i is the final product of good *i.* The following equivalence holds:

$$G_i = a_{i1}G_1 + a_{i2}G_2 + \cdots + a_{in}G_n + F_i$$

where a_{ij} is the technical coefficient representing the input of product *j* required to produce one unit of good *i.* If, for example, we set our target final output to 20,000 tons of coal and 1,000 tons of bread (and zero for iron and corn), then our resulting equations system is the following:

$$\begin{aligned}
G_{iron} &= 0.05\ G_{iron} + 0.1\ G_{coal} + 0.02\ G_{corn} \\
G_{coal} &= 2\ G_{iron} + 0.2\ G_{coal} + 0.5\ G_{bread} + 20000 \\
G_{corn} &= 0.1\ G_{corn} + 1.5\ G_{bread} \\
G_{bread} &= 1000
\end{aligned}$$

Solving this system give the value of gross output of every good needed to reach the desired final output. The solution of the above system is quite simple, since we have only 4 variables, and the resulting input-output table is the following:

Table 2: input-output table of a little economy. All quantities are expressed in tons.

Industry	**Inputs**				**Gross outputs**
	Iron	Coal	Corn	Bread	
Iron	185	7,416	0	0	**3,708**
Coal	3,490	6,979	0	0	**34,896**
Corn	33	0	167	0	**1,667**
Bread	0	500	1,500	0	**1,000**
Total intermediate	**3,708**	**14,896**	**1,667**	**0**	

However, a real economy is likely to have many more goods being produced than those of the example above. For instance, the economy of the USSR in the 80s was composed by roughly 20 million different goods, if we consider both intermediate and final output. When dealing with such huge systems, solution using Gaussian elimination is impracticable, since it requires n^3 multiplication operations, where n is the number of different products we have in the economy. A very time consuming task also for the most powerful supercomputers. However, we can take advantage of the sparseness of the system matrix, which makes the problem suitable for a solution with iterative numerical techniques, such as Gauss-Seidel or Jacobi. Let us assume that the number of different inputs used for the production of any single good is $n^{0.5}$. For instance, in a 20 million products economy every product has on average 4472 inputs. Computational complexity is now only $An^{1+0.5}$, where A is the number of iterations desired. If we consider a 20 million products economy and we want to run 10,000 iterations, Monte Rosa supercomputer in “Swiss national supercomputing centre” should theoretically do the job in a few seconds. Since its computing power is 402 TFlops,[28] a theoretical calculation gives a total of ca. 2.2 seconds of time for the arithmetical operations.[29]

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[28] http://www.cscs.ch/computers/monte_rosa/index.html

[29] We have seen that computational complexity is given by $An^{1+0.5}$. Therefore, in our case, we have $10{,}000*20{,}000{,}000^{1.5}$ operations. The computing power of Monte Rosa supercomputer is 402 TFlops, that is $402*10^{12}$ operations per second. With a simple division we get the theoretical performance time, that is ca. 2.2 seconds. However, it must be specified that this calculation doesn’t take into accounts other instructions, such as storing or retrieving a variable, etc.

5 Past experiences of planning and ICT

5.1 Soviet Union

In USSR planning was based on the concept known as “material balancing” and a nation-wide plan was developed every five years by Gosplan – the central planning agency. Gosplan specified a list of goods and services that were to be produced in the successive plan. However, the target list wasn’t composed of final outputs as in the method outlined in section 4.3; instead, the targets were set themselves in gross terms. It’s possible that this “gave rise to a sort of “productionism”, in which the generation of bumper outputs of key intermediate industrial products came to be seen as an end in itself”.[30]

Gosplan’s task was to ensure balance between available inputs and targeted outputs, and create a consistent plan. Drawing up a consistent plan for the whole Soviet economy was impossible, especially in the early years. Therefore, the plan considered only the most important industries, while others were handled on a more decentralized basis by regional authorities. In this respect, Lenin’s “commanding heights” was the notion that although only a limited portion of total output was under planners’ control, this was sufficient to exert a wide influence over the economy. In fact, the number of targets planned grew over time as planning became more sophisticated, but still in the mid-1980s Gosplan was able to draw up plans considering only 2,000 goods.[31] However, even under this simplification, planners had to deal with a lot of problems. The determination of technical coefficients turned out to be very difficult with the means available at the time, especially when considering that the coefficients had to be updated every time that a technical advance took place in a production process. In addition, handling second-round effects was really complicated, since – as we have seen – a great computation power is needed, even when considering only few target products. In light of these problems, planners were able to prepare maximum 2 or 3 consistent variants, and there was no reason to think they were the optimum.

The practice of delegation of planning also gave rise to big problems. For instance, in the mid-1980 when considering also the calculations of Gossnab[32] and of the industrial ministries, the items planned were circa 200,000.[33] Considering that the total items produced at the time in the Soviet economy were 24 million,[34] it appears clear that it was “possible for enterprises to fulfill their plans as regards the nomenclature of the items they have been directed to produce, failing at the same time to create products immediately needed by specific users”.[35] In planned economy, the specific output decisions made at the enterprise level should mesh properly (if enterprise A must produce an intermediate

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[30] A. Cottrell, P. Cockshott, *Socialist planning after the collapse of the Soviet Union*, 1993, p. 10.

[31] O. Yun, Improvement of Soviet Economic Planning, Moscow: Progress Publishers, 1988. Cited by P. Cockshott, A. Cottrell, *Economic planning, computers and labor values*, p.2.

[32] Gossnab was the state committee for material technical supply. This committee carried out more detailed planning.

[33] O. Yun, Improvement of Soviet Economic Planning. Cited by P. Cockshott, A. Cottrell, *Economic planning, computers and labor values*, p.2.

[34] O. Yun, Improvement of Soviet Economic Planning. Cited by P. Cockshott, A. Cottrell, *Economic planning, computers and labor values*, p.2.

[35] O. Yun, Improvement of Soviet Economic Planning. Cited by P. Cockshott, A. Cottrell, *Economic planning, computers and labor values*, p.2.

good needed by enterprise B, A must know the actual requirements to serve B with a useful product), but there was no guarantee in this sense, given also that it lacked an horizontal link between the enterprises.

5.2 Project “Cybersyn” in Allende’s Chile

Project Cybersyn was a Chilean project which took place under the Allende’s government in the years 1970 to 1973. The goal of the project was to develop a computer network to support the management of the nation-wide economy. Head of the project team was the British Stafford Beer, a pioneer researcher in the field of cybernetics. The team “designed cybernetic models of factories within the nationalized sector and created a network for the rapid transmission of economic data between the government and the factory floor”.[36]

The network was set up with a combination of microwave and telex links. All the key industrial centers were connected to a central “operations room” in capital Santiago. This enabled them to provide detailed data regarding production and employment of resources on a daily basis.

In the operations room information was presented on large screens, by means of different visualization techniques, while control buttons on the arms of the chairs could be used to interact with the screens, and highlight different features. Industries were shown as blocks, while flow lines represented interconnections between various industries. In addition, some bar graphs indicated for each industry the proportion of its capacity that was being used.

The availability of real-time data gave the government great opportunities for immediate decisions. In fact, in many countries economic data is gathered from a statistical office on a very wide periodic basis (for instance, 3 months) when compared with that enabled by Chile’s network. Therefore, government intervention to address a crisis is possible only some months after the crisis actually occurred. In this respect, there is no doubt that Chilean’s project was really pioneering.

Image 1: project Cybersyn's operations room in Santiago. Image taken from http://en.wikipedia.org/wiki/Project_Cybersyn.

Unfortunately, this interesting experiment ended already in 1973 when Pinochet took power by coup and the project was abandoned.

[36] E. Medina, *Designing Freedom, Regulating a Nation: Socialist Cybernetics in Allende’s Chile*, J. Lat. Amer. Stud. 38, p. 571, Cambridge University Press, 2006.

6 Conclusion

We have seen that the ECP was likely a big problem at the time when Mises wrote (1920) and till the end of 20^{th} century. Indeed, handling the problem requires calculating the allocation of inputs by means of input-output tables. To be effective, the calculation must consider all the products of the economy, which are in practical situations a huge quantity. The historical example of the Soviet Union illustrates the main problems that planners had.

However, the technology has progressed over the years, and we can say that in particular today's information and communication technology has the potential to enable alternative economic models that provide a solid solution to the ECP – one is Cockshott and Cottrell's model based on labor time. Such a system would be for sure more egalitarian and democratic than the capitalistic one – however, I think that its dynamic efficiency must be analyzed more in detail.

In addition, the role of ICT in the whole process is especially centered on enabling the following points: distributed decision making, detailed management at enterprise level, economic simulation with big data. Particular research area are also neural nets and their application in economics, input-output models for simulating economic systems, and resolution methods for large sparse linear systems of equations (which are researched especially in the fields of physics and astronomy).

In conclusion, the thesis' topic constitutes a broad interdisciplinary domain; however this seems to be little researched, maybe for the common belief that planned economy will unconditionally prove to be inefficient.

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