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Abstract

We study the welfare costs of inflation in a monetary general equilibrium model with networks in the labor market. Unemployment results when individuals are unsuccessful in hearing about job opportunities, either directly or through their peers. Inflation affects the consumption-leisure choice differently depending on job network structure. Inflation hits harder in more connected networks. In these networks, people consume more and enjoy more leisure, leading to higher welfare. Inflation reduces consumption and hurts households more when labor markets are more effective.

Keywords: Social networks, Labor market frictions, Inflation, Welfare costs of inflation

JEL Classification: D85; E31; E40; J64.

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1 Introduction

We study the welfare costs of inflation in a monetary general equilibrium model with a cash-in-advance constraint and networks in the labor market. Unemployment results when individuals are unsuccessful in hearing about job opportunities either directly or through their peers in a network, or when jobs exogenously break up. Different network structures lead to different levels of employment. The employment rate is lowest in an empty network (where no job information is transmitted), and employed households work more. In more connected networks, more people hear about jobs, the economy's employment rate increases, which leads to more output and consumption. Since more people are working, per capita hours worked falls, so agents also experience more leisure. For any given inflation rate, agents enjoy more leisure in more connected networks. Consumption and leisure are the highest in the regular network (uniform social information transmission), leading to higher welfare with this network.

Our model combines Cooley and Hansen (1989)'s monetary general equilibrium model with a cash-in-advance constraint with Calvó-Armengol and Jackson (2004) and Vega-Redondo (2007) model of the transmission of job offers in large, complex networks. Each agent is connected to others through a social network. Information about job opportunities arrives randomly. If an agent is unemployed, she will take the job. On the other hand, if the agent is already employed then she may pass job information along to a friend, relative or acquaintance. Workers are thus heterogenous with respect to their chances of finding a job, but not hours worked. That is, agents who have more links may expect to hear about jobs from their peers more often, and their employment status will evolve differently than that of an agent with fewer links. Once employed, workers supply the same number of hours and experience the same consumption.

Inflation distorts households allocations and its effect on the economy's welfare depends on the structure of the labor market. If unemployment results from the time-consuming and costly matching of vacancies with searching agents, Heer (2003) has shown that inflation may help to increase employment. Following a decline in consumption, the reservation wage of the households (and, the bargained wage) decrease. Firms increase their vacancies, which boosts employment. In the presence of search unemployment, welfare losses due to inflation are of small magnitude. In a cash-in-advance, Walrasian labor market economy of Lucas and Stokey (1987) or Cooley and Hansen (1989), higher inflation reduces the return from working as income earned in the previous period cannot be spent on the cash good until the next period. A higher money growth rate reduces steady state aggregate consumption and hours worked and, as a consequence, households substitute leisure for labor, and employment and output decline.

Network structures - the empty, regular and power-law networks - must be interpreted as different economies that are identical except for how job information flows from one worker to another. We show that the consumption-leisure substitution effect will depend crucially on the type of network in the labor market. In other words, the agents' ability to substitute from consumption towards leisure when inflation increases will be determined by how well people are connected and job information is transmitted: inflation hits harder more connected network economies. If agents are connected to more peers and job information flows better, labor markets are more effective (can better match workers to jobs) and income and substitution effects both lead to more consumption and leisure relative to a less connected network. In more connected networks, employment is higher, consumption is cheaper and is a relatively bigger share of agents' utility. In these economies, the negative impact of inflation on welfare is bigger. In these networks, inflation reduces consumption and welfare more.

The importance of social networks in labor markets has long been understood. Access to information about job opportunities is influenced by social structure and individuals use connections with others (e.g., relatives, friends, acquaintances) to build and maintain information networks. Networks in the labor market reduces job search frictions and increases employment. Empirical research indicates that a significant fraction of all jobs are found through contacts (see Holzer, 1988; Montgomery, 1991; Topa, 2001, Gregg and Wadsworth, 1996; Addison and Portugal, 2001) and firms use referrals extensively when trying to fill a vacancy. The job network literature has shown that social networks have important implications for the dynamics of employment, as well as the duration and persistence of unemployment (Calvó-Armengol and Jackson, 2004). By including agents who are heterogeneous in the number of peers they have in the labor market network, we introduce a very specific and tractable form of worker heterogeneity. It is this heterogeneity that drives differences in welfare costs of inflation between the types of networks we consider.

Measuring the welfare costs of inflation is an old issue in macroeconomics and has motivated a vast literature (Bailey, 1956; Cooley and Hansen, 1991; Dotsey and Ireland, 1996; Lucas, 2000; Serletis and Yavarib, 2004; Craig and Rocheteau, 2008; Chiu and Molico, 2010; Boel and Camera, 2011 and several others). To the best of our knowledge, this is the first paper to study welfare costs of inflation in the presence of networked labor markets. In Section 2 we describe the labor market dynamics governed by social networks. Section 3 and 4 provide a brief presentation of the model and calibration and the welfare cost estimates, respectively. Section 5 offers concluding remarks.

2 Employment rate and networks in labor markets

We assume there is a continuum of agent types $z \in [0, \infty)$ and agents are heterogenous with respect to the number of links they are connected to, i.e., an agent of type z has z peers in her social networks. Agents differ with regard to their chances of finding a job. That is, a job network process determines whether or not the worker hears about a job opportunity and actually works.

Information about job opportunities arrives randomly. Each agent hears about a job opening with probability $\gamma \in [0, 1]$. All jobs are identical and the job arrival process is independent across agents. If the agent is unemployed, she will take the job. On the other hand, if the agent is already employed then she may pass the information along to a friend, relative or acquaintance who is unemployed. The rate at which an employed worker passes information to each of her unemployed peers is given by $v \in [0, 1]$. Let ρ be the exogenous job break up probability, which is independent across agents.

Each agent may have peers to whom she passes information when employed, and from whom she may receive information when unemployed. These peers are connected to one another in a social network. A *network* is described by a symmetric matrix $\mathfrak{G}$, where $\mathfrak{g}_{ij} \in \{0,1\}$ denotes whether a link exists between agents i and j. That is, $\mathfrak{G}_{ij} = 1$ indicates that i and j know each other and $\mathfrak{G}_{ij} = 0$ otherwise. The relationship between i and j is reciprocal. The structure of this network $\mathfrak{G}$ will determine how information flows throughout from one agent to another, and will have a large impact on each family member's employment status. A key property of a network is its *degree distribution* $\{B_z\}_{z=0}^{\infty}$, where B_z is the proportion of agents who have z peers. A network's degree distribution summarizes much of its structure.

We focus on *large* networks where there are infinitely many nodes. As networks grow large, much of local information ceases to matter (Vega-Redondo 2007), so focussing on degree distributions is appropriate. We consider three cases: empty, regular and power-law. The empty and regular networks represent the cases of no and uniform social information transmission, respectively. Power-law networks result from the case where, rather than forming links randomly, agents have a preference for being linked to agents who already have many links. Workers with many links are more likely to be employed, and have access to job information. These networks exhibit the "small-worlds" properties of low average distances between agents - the "six degrees of separation" phenomenon - and dense "clusters" of connections identified by Watts (1999). These properties have been found in many important contexts, including scientific collaboration (Jackson, 2008) and email contact networks (Ebel et al., 2002).

To analyze the dynamics of employment, we apply the mean field approach, which assumes there are no correlations or neighborhood effects in information transmission. Our approach amounts to assuming the *average* state of the network is replicated *locally*, for every agent, so that the proportion of an agent's peers who are unemployed is given by the unemployment rate (Vega-Redondo 2007). This approach relies on the assumption that there are no systemic differences between each worker's local neighborhoods (*homogenous mixing*). Because the network is large, an agent could not infer anything about their employment status beyond the average in the network.

The employment rate of workers with z peers is n_z. Following the mean-field approach, the number of employed agents follows the law of motion:

$$\dot{n_z} = -\rho n_z + (1 - n_z)[\gamma + (1 - \gamma)z\theta v]. \tag{1}$$

The change in the level of employment has three main components. First, ρ percent of agents who are employed will lose their jobs. Second, a fraction γ of the unemployed agents will hear of a job themselves. Third, of those unemployed workers who do not hear of a job opportunity themselves, each of their z peers is employed with probability θ, and passes job information at rate v.

The probability an agent's peers are employed (θ) depends on the average degree in the network $\langle z \rangle$, the number of links each of these peers have (z), the proportion of agents who have z peers (B_z) and the employment rate of agents with z links (n_z), as follows:

$$\theta = \frac{1}{\langle z \rangle} \int_{z=1}^{\infty} (z n_z B_z)\, dz \tag{2}$$

where $\langle z \rangle = \int_0^{\infty} (z B_z)\, dz$ is the average degree in the network. Note that the probability your peers have z links is not equal to the proportion of the population that has z links (agents with many links, and a large z, are disproportionately likely to be your peers).

The employment rate of the economy n_t follows an exogenous stochastic process, which is a function of the state of the network $S = \{\rho, \gamma, v, B_z\}$. Since the employment rate n_{zt} may be different for agents with different number of links z, the economy's average employment rate is expressed as follows:

$$n_t = \int_{z=1}^{\infty} (n_{zt} B_z)\, dz, \tag{3}$$

If the economy converges to a steady state, the change in the level of employment is equal to zero, i.e., $\dot{n_z} = 0$ for all z. The number of newly employed agents of each type z is exactly equal to the number of newly unemployed agents, and the economy will remain at this level of employment indefinitely. We take this *long run prevalence* of employment to be the economy's employment rate (Vega-Redondo, 2007).

Setting $\dot{n}_z = 0$ in equation (1), we find the steady state level of employment satisfies

$$n_z^* = \frac{\gamma + (1-\gamma) z\theta^* v}{\rho + (\gamma + (1-\gamma)\, z\theta^* v)} \tag{4}$$

and, according to equation (2), $\theta^* = \frac{1}{\langle z \rangle} \int_{z=1}^{\infty} (z n_z^*)\, dz$.

Then, the long run steady state employment rate is defined as follows:

$$n^* = \int_{z=1}^{\infty} (n_z^* B_z)\, dz. \tag{5}$$

For different degree distributions $\{B_z\}_{z=1}^{\infty}$, the long run steady state employment rate, equation (5), may have different solutions. In regular networks, where every agent has the same number of peers k, $B_z = 1$ for $z = k$, and $B_z = 0$ for all other z. Each worker is exactly the same, so that $\langle z \rangle = k$. For $k = 0$, this is the empty network (our baseline), and may be taken as a worst case scenario, where each worker must hear of a job themselves, at the exogenous arrival rate γ. The power-law network has distribution $B_z = (\alpha - 1) z^{-\alpha}$, and there are many more agents who have very many links, the "fat tail" of the power-law distribution.

The economy's long run employment rate for a regular network n^R is equal to the employment rate of the agents with k links, i.e., $n^R = n_k^R$, where n_k^R is the solution of the following expression:

$$n_k^{*R} = 1 - \rho \left\{ \gamma + \rho - (1-\gamma) \left[1 - \left(1 - \frac{avn^*}{\langle z \rangle} \right)^k \right] \right\}^{-1} \tag{6}$$

For the empty network, $k = 0$ and this expression simplifies to $n_{k=0}^E = \gamma/(\rho+\gamma)$, while for the regular network is is the root of a k-degree polynomial. For the power-law network, no analytical solution to equation (5) exists, and it must be characterized numerically.

3 Welfare cost of inflation and networks

In our economy, agents who have more links may expect to hear about jobs from their peers more often, and their employment status will evolve differently than that of an agent with fewer links. Once employed, workers provide the same number of hours and experience the same consumption. Hence, agents are heterogenous with respect to their chances to get a job, not hours worked.

A type z agent's expected utility in period t is given by

$$\begin{aligned} u(c_t, h_t) &= \ln c_t + n_{zt} A \ln(1-h_t) + (1-n_{zt}) A \ln(1) \\ &= \ln c_t + n_{zt} A \ln(1-h_t) \end{aligned} \tag{7}$$

where n_{zt} is the employment rate of agents with z links. The timing of the model is such that at the beginning of each period, employed workers (those that started the period with a job and those that just heard about and got a job) choose h. Unemployed workers neither actively search for a job nor engage in job related social networking activities.

There is a single firm in our economy with access to a technology described by a standard Cobb-Douglas production function $Y_t = k_t^{\epsilon} (n_t h_t)^{1-\epsilon}$, where $\epsilon \in (0,1)$ is the capital income share. Factors of production are paid their marginal products, i.e. $F_k(t) = r_t = \epsilon \left({n_t}^{1-\epsilon}\right) k_t^{\epsilon-1} h_t^{1-\epsilon}$ and $F_h(t) = w_t = (1-\epsilon)\left({n_t}^{1-\epsilon}\right)(k_t)^{\epsilon} h_t^{-\epsilon}$, where $F_k(t)$ and $F_h(t)$ denote the marginal product of capital and labor, respectively, r_t is the real rate of return on capital and w_t the wage rate for labor. We abstract from any technology shocks.

We follow Cooley and Hansen (1989) and normalize the three nominal variable in each period by dividing them by M_t and define $\hat{p}_t = p_t/M_t$, $\hat{m}_t = m_t/M_t$ and $M_t/M_t = 1$, where p is the economy's price level, m the household's money holdings and M the per capita money stock. Hence, the Lagrangian for the household's problem is

$$\pounds = \max_{\{c_t, k_{t+1}, h_{zt}, \hat{m}_t\}} E_0 \sum_{t=0}^{\infty} \beta^t \left[\begin{array}{c} \ln c_t + n_{zt} A \ln(1-h_t) + \mu_t^1 \left(\hat{p}_t c_t - \frac{\hat{m}_{t-1} + g_t - 1}{g_t} \right) \\ + \mu_t^2 \left(k_{t+1} + \frac{\hat{m}_t}{\hat{p}_t} - w_t h_t - (r_t + 1 - \delta) k_t \right) \end{array} \right] \tag{8}$$

where k is the capital holdings, g the gross growth rate of money, r and w are real and wage rates, respectively. The Lagrange multipliers for the cash-in-advance constraint and the household consumer budget constraints are μ_t^1 and μ_t^2, respectively.

Solving the Lagrangian (8) and assuming a stationary state equilibrium, we obtain the six equations that characterize the solution to the household problem. The stationary state consumption, price level, capital stock, hours worked and output are affected not only by the rate of growth of the money supply (g^*) but also by the long run steady state employment rate (n^*), which is a function of the job network process.

Network structures - the empty, regular and power-law networks - must be interpreted as different economies that are identical except for how job information flows from one worker to another. The impact of inflation on the economy's welfare will depend crucially on how agents are connected to each other. In networks with a higher average number of links, each worker has access to more peers, who will in turn be more likely to be employed, and thus more able to pass job information.

Since the economy's employment rate (n^*) is increasing in the average number of peers (m) agents have and the stationary state discounted utility is given by

$$U^* = \sum_{t=0}^{\infty} \beta^t \left[\ln C^* + n^* A \ln\left(1 - H^*\right)\right] = \frac{\ln C^* + n^* A \ln\left(1 - H^*\right)}{1 - \beta}, \tag{9}$$

agents tend to work less (enjoy more leisure), consume more and experience higher utility as the (average) number of peers increases. Hours worked are decreasing in the long run steady state employment rate, while consumption is increasing. Both hours worked and consumption are decreasing in the money growth rate. For a given job network process, i.e. an average number of peers m and the implied employment rate n^*, there are, as expected, welfare losses associated with inflation. However, the effects of a change in the inflation rate, as resulting from a change in the growth rate of money supply, on the economy's welfare depend crucially on the employment rate and how job information is transmitted. We study this relationship numerically in the next section.

4 Calibration and results

We set the parameters describing preferences and technology to the same values used in Cooley and Hansen (1989). The period over which individuals are constrained is a quarter and we set $\beta = 0.99$, $\epsilon = 0.36$ and $\delta = 0.025$. The value of the parameter A is chosen such that model predictions of output, consumption, capital stock and expected hours worked in the empty network (our baseline) are close to Cooley and Hansen (1989)'s model when $g = \beta$. The parameters for the network process ($\gamma = 0.40$, $\rho = 0.30$, $v = 0.05$) are such that the employment rate in the empty network is $n^* = 0.5714$.

The steady-state values for output, consumption, hours worked and welfare cost associated with various annual inflation rates are presented in Table 1. The welfare cost measure used is based on the increase in consumption that an individual would require to attain the level of utility under the Pareto optimal allocation ($g = \beta$) in a particular network, and numbers are expressed as a percent of steady-state real output, i.e., ($\Delta C/Y \times 100$). Table 1 presents the results for average number of peers $m = 2$ and $m = 40$.

The employment rate is lower in the empty network and employed households work more. For any given inflation rate, agents enjoy more leisure in more connected networks. Steady-state welfare is highest in the regular network; consumption and leisure are the highest, leading to higher welfare than in other networks. When more people hear about jobs, the economy's employment rate increases which leads to more output and consumption. Since more people are working, per capita hours worked falls and agents experience more leisure. Essentially, with better labor market networks, workers are able to enjoy more of both consumption and leisure.

The welfare cost of inflation is larger in the presence of social networks. For instance, the welfare cost of a moderate (10%) inflation is 0.1878 percent of the economy's output in an empty network economy and 0.2132 percent in the power-law economy ($m = 40$). These estimates may be compared to those obtained under different labor market structures. In the Walrasian labor market of Cooley and Hansen (1989), depending on the measurement of money by either the monetary base or M1, the welfare costs of a reduction from an annual inflation rate of 10 percent to the optimal rate is approximately $0.1 - 0.4$ percent of GNP. Assuming labor market frictions in the form of search unemployment, Heer (2003) shows that a reduction of benchmark money growth of 1.3 percent to zero results only in a small utility gain of 0.03 percent.

Table 1 - Networks, Allocations and Welfare Cost of Inflation

			Annual Inflation Rate				
			-4%	0%	10%	100%	400%
		$g =$	β	1.00	1.024	1.19	1.41
	Empty	Output Y^*	1.0969	1.0916	1.0791	0.9997	0.9108
$n = 0.5714$		Consumption C^*	0.8157	0.8117	0.8024	0.7433	0.6773
		Hours H^*	0.5183	0.5158	0.5098	0.4723	0.4303
		Welfare Cost	0.0000	0.0519	0.1878	1.4993	3.9541
$m = 2$	*Power-Law*	Output Y^*	1.1161	1.1106	1.0977	1.0156	0.9240
$n = 0.5910$		Consumption C^*	0.8300	0.8259	0.8162	0.7552	0.6871
		Hours H^*	0.5099	0.5073	0.5014	0.4639	0.4221
		Welfare Cost	0.0000	0.0528	0.1911	1.5245	4.0178
$m = 2$	*Regular*	Output Y^*	1.1169	1.1114	1.0984	1.0162	0.9245
$n = 0.5918$		Consumption C^*	0.8305	0.8264	0.8168	0.7556	0.6875
		Hours H^*	0.5095	0.5070	0.5011	0.4636	0.4218
		Welfare Cost	0.0000	0.0528	0.1912	1.5255	4.0204
$m = 40$	*Power-Law*	Output Y^*	1.1484	1.1426	1.1289	1.0422	0.9460
$n = 0.6255$		Consumption C^*	0.8540	0.8496	0.8394	0.7750	0.7035
		Hours H^*	0.4957	0.4932	0.4872	0.4498	0.4083
		Welfare Cost	0.0000	0.0543	0.1966	1.5667	4.1248
$m = 40$	*Regular*	Output Y^*	1.2463	1.2394	1.2233	1.1222	1.0114
$n = 0.7432$		Consumption C^*	0.9267	0.9216	0.9096	0.8345	0.7521
		Hours H^*	0.4527	0.4502	0.4444	0.4076	0.3674
		Welfare Cost	0.0000	0.0589	0.2132	1.6941	4.4459

m: average number of peers; n: economy's employment rate.

Different network structures lead to different levels of employment, and thus to different welfare losses from inflation. In more connected networks, labor markets are more effective (better to match workers to jobs) and income and substitution effects both lead to more consumption and leisure. Consumption is cheaper and it is a relatively bigger share of agents' utility. In these economies, people consume more and the effect of a rise in the cost of consumption is bigger. Inflation affects consumption and hurts households more. On the other hand, in less connected network economies, the impact of inflation on consumption is smaller since people are already consuming relatively less. Leisure is relatively cheaper and households can more easily substitute it for consumption. Hence, when due to inflation people have to substitute from consumption towards leisure, the amount of consumption they have to give up is relatively larger in more connected network economies.

Inflation has stronger (negative) effects on the economy's welfare the more peers people have and the more homogeneous the network is. Figure 1 illustrate the welfare cost when inflation increases from zero to ten percent and the average number of peers (m) ranges from two to forty. Employment and welfare losses from inflation are lower in the empty network (where no job information is transmitted) than in the regular network (uniform social information transmission).

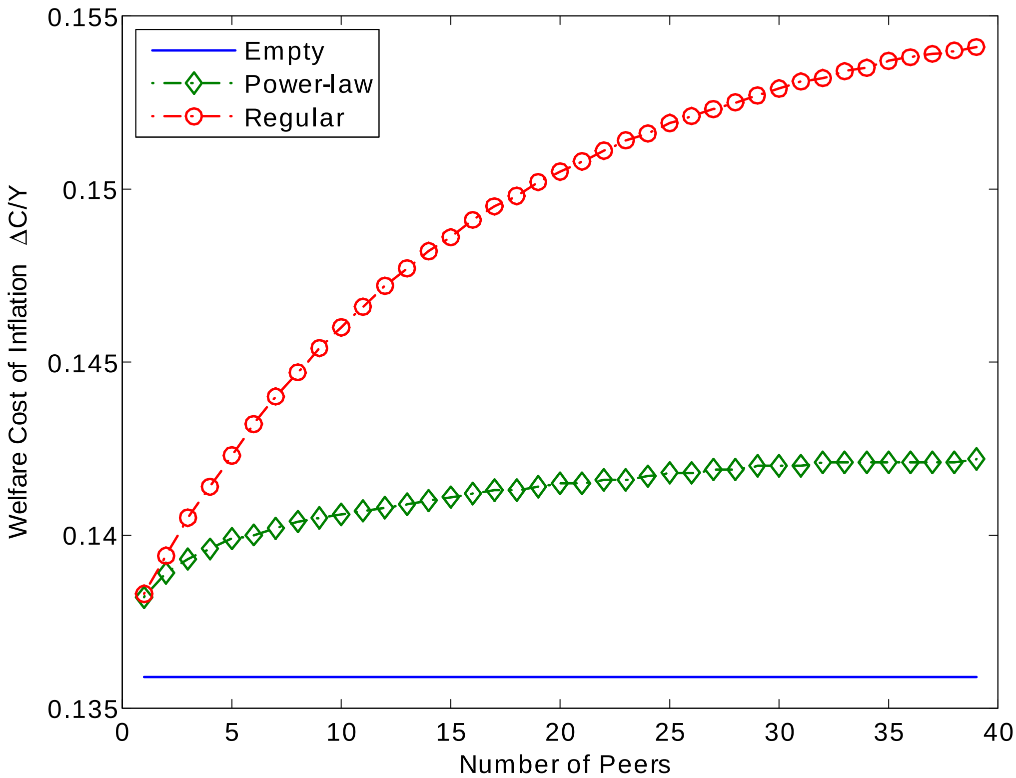

Figure 1 - Welfare cost of 10% inflation by average number of peers (m) in different networks

The power-law networks, with their heterogeneous populations, have a few agents with a very high number of peers. These agents provide employment opportunities at a high rate, but employment is lower than in the regular network and welfare losses from inflation are thus lower as well. A comparison of welfare costs of inflation across different networks for an average number of peers $m = 100$ is illustrated in Figure 2. As inflation rises, the relative cost of inflation rises fastest in the most connected network, the regular network.

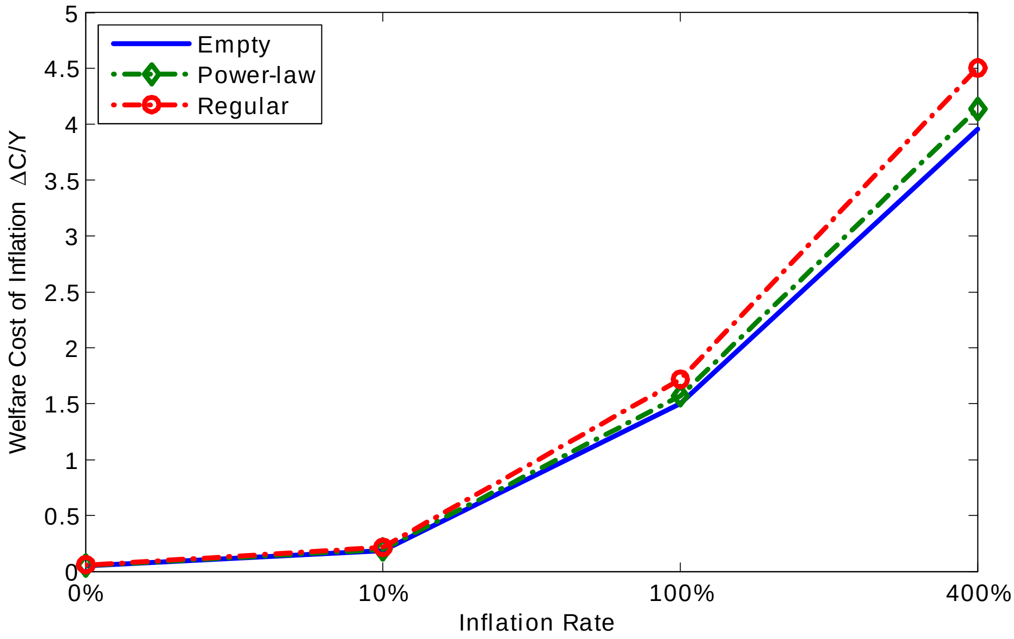

Figure 2 - Welfare cost of inflation across different networks ($m = 100$)

5 Conclusion

Inflation distorts households allocations and its effect on the economy's welfare depends on the structure of the labor market. In our model, the economy's employment rate is determined by networks in the labor market. In more connected networks, job information flows better. Consumption and leisure are the highest, leading to higher welfare in the regular network (uniform social information transmission). Inflation affects the consumption-leisure choice differently depending on job network structure. The effect of inflation on the economy's welfare depends crucially on the number of peers people have and how job information flows from one peer to another. Inflation has a strong effect on welfare, i.e., larger welfare losses, the more peers people have on average and the more homogeneous the population is. The negative impact of inflation on welfare is bigger in more connected networks.

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